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ABSTRACT

This final report reviews the main theoretical and empirical developments concerning components of individual differences in human intelligence. The report is divided into three main sections. The first briefly reviews alternative approaches to understanding the nature of intelligence. The second provides the proposed componential metatheory, a view of human intelligence whereby intelligence is understood in terms of the functioning of various kinds of information-processing components, and in terms of the interactions among and automatization of these components. The basis of the componential view is the functioning of the metacomponents, or executive processes, which directly activate and receive feedback from other kinds of components; in particular, components of performance, acquisition, retrieval, and transfer. The third and main section describes various aspects of the componential theory and tests of this theory. This last section covers inductive and deductive reasoning. (Author/PN)

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Components of Individual Differences in Human Intelligence

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Final Report
February, 1983

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deductive reasoning. The report closes with some conclusions and suggested directions for future research.

Components of Individual Differences in Human Intelligence

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FINAL REPORT

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Abstract

This report constitutes the Final Report for ONR Contract N0001478C0025. It reviews the main theoretical and empirical developments that arose from this contract. The report is divided into three main sections. The first briefly reviews alternative approaches to understanding the nature of intelligence. The second provides the proposed componential metatheory. The third and main section describes various aspects of the componential theory and tests of this theory. This last section covers inductive and deductive reasoning. The report closes with some conclusions and suggested directions for future research.

Components of Individual Differences in Human Intelligence

During the twentieth century, a great diversity of approaches has emerged to the understanding of human intelligence. I describe here one of these approaches, which I refer to as the "componential approach." My presentation of the approach is divided into four main parts. The first part, an introduction, sets an historical and contemporary context in which the present proposals may be viewed. The second part presents a componential metatheory or framework, providing a description of the basic mechanisms that are proposed to constitute the human intellectual system. The third part provides theory derived from the componential point of view, and data collected to test the theory. The fourth part draws some general conclusions from the metatheory, theory, and data.

In recent years, two of the most influential approaches to understanding intelligence have been the psychometric and the information-processing approaches. My own approach, and that of many other contemporary investigators, can be seen as a synthesis of these two important approaches. (See, for example, Hunt, 1978, for another approach that synthesizes psychometrics and information processing in a different way.) Each of the psychometric and information-processing approaches has sought to understand the nature of intelligence in somewhat different, although not mutually exclusive, terms. These terms are considered below.

Approaches to Understanding the Nature of Intelligence

The psychometric approach to understanding the nature of intelligence dominated theory and research in the first half of the century. Investigators using this approach sought to understand intelligence by analyzing patterns of individual differences in scores on various kinds of mental tests, such as vocabulary, number series, figural analogies, mental rotation of geometric objects, and the like. The basic idea was that underlying scores on these manifest measures of mental abilities were one or more latent abilities that gave rise to the observable individual differences in test scores. If these latent sources of individual differences could be identified, then the structure of human intelligence could in some sense be understood. A statistical procedure called "factor analysis," which analyzes observable patterns of individual differences in terms of hypothesized latent constructs or "factors," was used to make the hoped for identification.

A number of different factorial theories of human intelligence have been proposed that differed both in terms of the numbers and the identities of the factors indicated. At the lower end of the scale of factor numerosity, Spearman (1927) proposed that intelligence could be understood in terms of a general factor ("g")--which he tentatively identified as attributable to individual differences in mental energy--and a set of essentially uninteresting and clearly subordinate specific factors, each of which was relevant only to individual differences in the performance of a single task. Spearman's theory thus emphasized just a single factor of intelligence. At the upper end of the scale, Guilford (1967) proposed that intelligence could be understood in terms of 120 factors, which differed in terms of the operations, contents, and products they represented. An example of a factor in Guilford's system would be cognition (process) of figural (content) relations (product), which is used to infer the nature of relationships between two figural terms, as in a figural analogy.

Most factorial theories of intelligence fall between the extremes of Spearman and Guilford in the numbers of factors they propose. Thurstone's (1938) well-known theory of primary mental abilities, for example, posits seven factors, namely, verbal comprehension, word fluency, number facility, spatial visualization, reasoning, perceptual speed, and memory.

Despite its initial popularity among investigators of intelligence, the psychometric approach to understanding intelligence has become a source of increasing disenchantment during the latter half of the twentieth century. The full range of reasons for this disenchantment are too numerous and complex to consider in detail here (but see Carroll, 1978; Sternberg, 1977b). The main reasons, stated briefly, seem to have been (a) difficulties in distinguishing among and in empirically disconfirming alternative factorial theories, especially through the use of factorial methods, (b) the almost exclusive reliance of factorial methods upon individual differences for the identification of the constructs constituting intelligence, with the concomitant assumption that a structure can be a constituent of intelligence _only if_ it generates observable individual differences in task performance, and (c) the failure of factorial methods directly to identify the processes that combine to constitute task performance. The structural model of factor analysis seems to provide a useful, but incomplete perspective on intellectual performance. A further perspective seems to be needed that will shed light on process as well as structure. The information-processing approach seems to provide such a perspective.

The information-processing approach to human intelligence seeks to understand intelligence in terms of the underlying processes that in various combinations constitute intelligent task performance. Although the primary emphasis of the approach is upon process identification, the approach seeks also to identify the speeds and difficulties with which these processes are executed, the strategies for task performance into which the processes combine, the mental representatives upon which the underlying processes and strategies act, and the allocation of attention and other processing resources to various aspects of a given task.

Whereas various psychometric theories of intelligence are usefully distinguished in terms of the numbers and identities of the factors they propose, various information-processing theories are usefully distinguished in terms of what might be referred to as the "level of processing" to which they seek to ascribe the antecedents of intelligent performance, with levels ranging from the perceptual-motor level to the level of complex problem solving. Whereas no sensible theorist would seek to account for all intelligent behavior in terms of processes operating at just a single level (or narrow range of levels, since levels are best conceived of as continuous), most theorists seem to emphasize a single level or a fairly narrow adjacent set of levels in their theories. Although most theorists emphasize a particular set of levels, they generally also attempt to deal at least somewhat with a broader range of processing. At the extreme of simplicity can be found the theory of Jensen (1979). Jensen has sought to understand intelligence in terms of very simple perceptual-motor information processing, as is found in simple reaction time (time to offer a single response to a single stimulus) and choice reaction time (time to offer one of several possible responses to one of several possible stimuli). At the extreme of complexity can be found theories such as those of Anderson (1976), Newell and Simon (1972), and Schank (1980), which have sought to explain intelligence primarily in terms of complex language understanding (e.g., sentence and story comprehension) and problem solving (e.g., logical theorem-proving and chess performance). At levels in between these two extremes can be found theories such as Hunt's (1978, 1980), which is closer to the "simpler" end of the continuum and which seeks to understand intelligence partly in terms of speed of access to lexical codes stored in long-term memory (e.g., the name of the letter "A"), and theories such as my own (Sternberg, 1979, 1980d, 1981b, d), which is closer to the more "complex" end of the continuum and which seek to understand intelligence primarily in terms of reasoning and verbal comprehension (e.g., the solution of analogies and the figuring out of the meaning of a previously unknown word encountered in a natural context, such as a newspaper article). Having placed my own theory in the context of some others, I shall proceed to a brief description of the metatheory underlying the theory, and then shall consider jointly the theory and the data that have been collected to test various aspects of it.

Componential Metatheory

The basic unit in my own theory is the component process. Each process or "component," has three important properties associated with it: duration, difficulty (i.e., probability of its execution eventuating in an erroneous result), and probability of execution. The three properties are, at least in principle, independent. For example, a given component may take a rather long time to execute, but may be rather easy to execute, in the sense that its execution rarely leads to an erroneous or otherwise inadequate outcome; or the component may be executed quite rapidly, and yet be rather difficult to execute, in the sense that its execution often leads to an error. Consider, for example, "mapping," one component used in solving analogies such as LAWYER is to CLIENT as DOCTOR is to (a) PATIENT or (b) MEDICINE. Mapping calls for the discovery of the higher-order relation between the first and second halves of the analogy. The component has a certain probability of being executed in solving an analogy, and, if executed, it has a certain duration and a certain probability of being executed incorrectly.

Kinds of Components

Components can be classified by the kind of function they perform. I shall consider each function in turn.

Metacomponents are higher-order control processes used for executive planning and decision making in task performance. Collectively, they are sometimes referred to by psychologists as the "executive" or the "homunculus." The ten metacomponents that I believe are most important in intelligent functioning are (a) recognition that a problem of some kind exists, (b) recognition of just what the nature of the problem is, (c) selection of a set of lower-order components for performing a task, (d) selection of a strategy for task performance into which to combine the lower-order components, (e) selection of one or more mental representations for information, (f) decision as to how to allocate attentional resources, (g) monitoring, or keeping track of one's place in task performance, and of what has been done and what needs to be done, (h) understanding of internal and external feedback concerning the quality of task performance, (i) knowing how to act upon the feedback that is received, and (j) actually acting upon the feedback. Note that this last metacomponent in effect assigns a crucial role to action in the theory of intelligent performance. I do not believe that one can have an adequate theory of intelligence without considering both thought and the actions that emanate from it.

Performance components are lower-order processes used in the execution of various strategies for task performance. Because the bulk of the next section of this article will deal with various performance components and their roles in task performance, only one example of a performance component will be given here (to supplement the example of "Mapping," a performance component briefly described earlier). The example is that of inference, the component by which an individual figures out similarities and differences between or among a set of objects. (In contrast, mapping involves figuring out higher-order relations between or among lower-order relations.)

Acquisition components are processes involved in learning new information and storing it in memory. An example of such a component is rehearsal of words in a to-be-learned list. Retrieval components are processes involved in accessing information that has already been acquired and stored in memory, for example, accessing a lexical code. Transfer components are processes involved in generalizing stored and retrieved information from one situation to another, for example, recognizing that two different terms mean the same thing. As of yet, the processes of transfer are but poorly understood.

The various kinds of components considered above are applied in task performance toward the reaching of a solution or other goal. Components can vary greatly in the range of tasks to which they apply. Some components, and especially the metacomponents, appear to be broadly applicable over a wide range of tasks. Other components apply to only a narrow range of tasks; such components are of little theoretical interest, and generally of little practical interest as well. My concern here will be only with components that I believe are fairly generalizable over a wide range of tasks.

Interactions among Components

The various kinds of components described above are theorized to be highly interactive. Four kinds of interactions need to be considered: direct activation of one kind of component by another kind; indirect activation of one kind of component by another kind via the mediation of a third kind of component; direct feedback from one kind of component to another kind; and indirect feedback from one kind of component to another kind via a third kind. In the proposed system, only metacomponents can directly activate and receive feedback from each other kind of component. Thus, all control passes directly from the metacomponents to the system, and all information passes directly from the system to the metacomponents. The other kinds of components can activate each other only indirectly, and receive feedback from each other only indirectly; in every case, mediation must be supplied by the metacomponents. For example, the acquisition of information affects the retrieval of information and the various kinds of performances that can be done upon that information, but only via the link of the three kinds of components to the metacomponents. Information from the acquisition components is filtered to the other kinds of components through the metacomponents. Metacomponents are also unique among the various kinds of components in that they can directly activate and receive feedback from each other.

Consider a simplified example of how the proposed system might function in the solution of a word puzzle, such as an anagram (where the letters of the word are presented in scrambled fashion). As soon as one decides metacomponentially upon a certain tentative strategy for unscrambling the letters of the word, activation of that strategy can pass directly from the metacomponent responsible for deciding upon a strategy to the performance component responsible for executing the first step of the strategy, and subsequently, activation can pass to the successive performance components needed to execute the strategy. Feedback will return from the performance components indicating how successful the strategy is turning out to be. The individual must decide how to act upon this feedback, and then must actually perform the required actions.

As a given strategy is being executed, new information is being acquired about how to solve anagrams, in general. This information is also fed back to the metacomponents, which may act upon or ignore this information. New information that seems useful is more likely to be directed back from the relevant metacomponents to the relevant transfer components for use in later anagram (or other) problems, as needed. Thus, failure to transfer information may be due to inadequate operation of transfer components, but alternatively, it may be due to inadequate metacomponential activation, inadequate feedback to metacomponents from performance components, or inadequate functioning of acquisition components that are responsible for learning the information in the first place. Such is the nature of an interactive system.

The metacomponents are able to process only a limited amount of information at a given time. In a difficult task, and especially a new and different one, the amount of information being fed back to the metacomponents may exceed capacity to act upon that information. In this case, the metacomponents become overloaded, and valuable information that cannot be processed may simply be wasted. The total information-handling capacity of the metacomponents of a given system will thus be an important limiting aspect of the system. This capacity can effectively be increased by automatization of component execution. Automatic processing of information is theorized to require far less in the way of attentional resources than is required by controlled processing (see Sternberg, 1981a).

To summarize, it has been proposed that human intelligence can be understood in terms of the kinds of components constituting its functioning, and in terms of various kinds of interactions among those kinds of components. In the next section, it is shown how the kind of componential viewpoint presented here can be applied concretely to the understanding of intelligent task performance.

Componential Theory and Empirical Tests

Over the past several years, my collaborators and I have been engaged in developing a componential theory of human intelligence that uses as its conceptual foundation the metatheory described above. The goal has been to provide an integrated, and in some respects, unified account of human intellectual functioning. Although we have studied a number of different tasks requiring a number of different components of information processing, performances on the tasks are theorized minimally to have in common (a) the kinds of components (metacomponents, performance components, acquisition components, retrieval components, transfer components) relevant to task performance, with their attendant properties of duration, difficulty, and probability of execution, (b) the particular (ten) metacomponents noted earlier, which are applicable to functioning in virtually any cognitive task, and (c) the scheme of interaction among the various kinds of components, also as noted earlier. Hence, the metacomponential framework provides one unifying set of constructs for understanding what is common across essentially the full range of intellectual tasks.

What makes intellectual tasks more or less similar to each other in their information processing requirements is the degree of overlap in the performance components utilized in task execution. Hence, the particular theories of task performance to be described provide a basis for understanding why performances on certain kinds of tasks can be viewed as more or less interrelated, both from the point of view of shared information processes and the point of view of correlated patterns of individual differences. On this view, the psychometric factors representing common sources of individual differences across tasks are derivatives, in some sense, of shared information processes across these tasks. What, exactly, are these information processes, and how are they shared across tasks? It is to a consideration of these issues that I will shortly turn.

It is useful, for our present purposes, to divide our consideration of intellectual abilities into three broad classes: fluid abilities, crystallized abilities, and social/practical abilities. Fluid abilities are skills involved in the solution of problems such as figural analogies, number series, and verbal classifications of related terms. Crystallized abilities are the skills and knowledge drawn upon in the performance of tests of things such as vocabulary, reading comprehension, and general information. Social/practical abilities are skills used in the everyday socio-cultural problems one faces in one's life. There are three interrelated reasons why this particular classificatory scheme makes sense. First, at least the first two aspects of it, and to a lesser extent, the third, seem to correspond well to the broad "group factors" (factors spanning wide groups of tests, but not the entire range of tests) that have emerged in psychometric research (e.g., Cattell, 1971; Horn, 1968; Vernon, 1971). Second, our research and that of others suggests that this particular scheme comes close to maximizing the similarity of the performance components used in tasks measuring any one of these three constellations of abilities while maximizing the dissimilarity of the performance components used across tasks from different ones of the three constellations of abilities (e.g., Pellegrino & Glaser, 1980; Snow, 1978; Sternberg, 1980d). And third, it so happens that if one assesses people's implicit theories (internalized conceptions) of the nature of intelligence, these three constellations happen to characterize the implicit theories of both laypersons and experts in the field of intelligence (Sternberg, Conway, Ketron, & Bernstein, 1981). Consider now what some of the performance components are that constitute abilities in the first of these domains, fluid abilities. This is the domain to which I and many other theorists of intelligence have so far devoted the most attention. For organizational convenience and further reasons of psychological theory, my discussion of fluid abilities will be subdivided into separate sections on induction and deduction.

Fluid Abilities: Induction

Our investigations of fluid abilities of inductive reasoning have led us to the analysis of a number of tasks, including analogies (Sternberg, 1977a, 1977b; Sternberg & Nigro, 1980; Sternberg & Rifkin, 1979); series completions (Sternberg & Gardner, 1982, 1983); classifications (Sternberg & Gardner, 1982, 1983); metaphorical understanding and appreciation (Sternberg, Tourangeau, & Nigro, 1979; Tourangeau & Sternberg, 1981, 1982); causal inferences (Schustack & Sternberg, 1981); and projection of future events (Sternberg, 1981b, 1982). For the purposes of this summary overview, I will discuss each of these tasks briefly, describing first the theory underlying it and then the data that have been collected to test the theory.

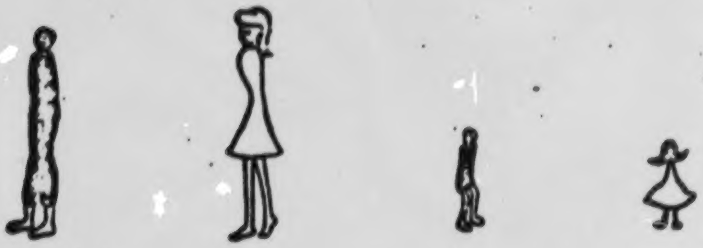
Theory of analogical reasoning processes. My first investigations of fluid abilities—indeed, of any mental abilities--were of analogical reasoning abilities. In its present form, my theory states that analogical reasoning can be decomposed into seven underlying performance components, which I will illustrate by drawing upon the simple analogy, LAWYER is to CLIENT as DOCTOR is to (a) MEDICINE, (b) SICK PERSON. The seven components are (a) *encoding*, by which the individual recognizes the terms of the problem and accesses attributes of the analogy terms that are stored in semantic memory and that might be relevant to task solution, (b) *inference*, by which the individual figures out the relationship between the first two terms of the analogy (e.g., that a lawyer renders professional consulting services to a client), (c) *mapping*, by which the individual figures out the higher-order relation between the two halves of the analogy (e.g., that both a lawyer and a doctor render professional services), (d) *application*, by which the individual takes the relationship inferred between the first two terms in the first half of the analogy as mapped to the third term in the second half of the analogy and uses this relationship to generate an "ideal" completion to the analogy (e.g., the individual might generate PATIENT as an ideal completion), (e) comparison, by which the individual compares each of the given answer options (in multiple-choice analogies) to the ideal, and decides which is better (in the sense of more closely resembling the ideal) e.g., the individual will compare each of MEDICINE and SICK PERSON to PATIENT, (f) justification, by which the individual decides whether the preferred answer option is close enough to the ideal option to warrant its selection, or whether instead the possibility ought to be entertained and possibly acted upon that an error has been made in earlier information processing (e.g., the individual might decide that SICK PERSON, although not an ideal response, is at or above some criterion for a minimally acceptable response), and (g) response, by which the individual communicates his or her choice of an answer (e.g., the individual might circle or press a button indicating his or her choice of SICK PERSON as the preferred answer).

I initially tested this theory of information processing (minus the comparison component, which had not yet become part of the theory at the time) under the assumptions that (a) the components were combined sequentially (serially) and that (b) they acted upon an attribute-value mental representation for information, meaning that each analogy term could be decomposed into a set of attributes with some range of possible values on each attribute, for example, height: tall-short. Alternative models were tested that varied in terms of which components of the theory were exhaustive (all encoded attributes processed, and which self-terminating (only a proper subset of the encoded attributes processed), and alternative theories were also tested that differed in the numbers of components theorized to be needed for analogy solutions.

Subjects in the first set of experiments were Stanford undergraduates. One group of 16 subjects solved 1152 schematic-picture analogies and 68 verbal analogies; a second group of 24 subjects solved 90 geometric analogies. An example of each of the three kinds of items is shown in Figure 2. Note that the schematic-picture and verbal analogies were presented in a true-false format, and the geometric analogies were presented in a forced-choice format. The primary dependent variable was response time (with error rate serving as a secondary dependent variable) and the independent variables were manipulations of various aspects of item difficulty that were needed in order to separate parameters representing durations of the theorized component processes. Subjects were tested tachistoscopically, meaning that they sat in front of a large box-like contraption that presented stimuli, measured response time, and recorded response choices. Tachistoscopic testing was followed by paper-and-pencil testing on psychometric measures of reasoning and perceptual-motor speed abilities.

Insert Figure 2 about here

Theory testing was accomplished via mathematical modeling. Each alternative theory and model was initially expressed as an information-processing flow-chart representing each performance component as a box in the chart. These models were then quantified by assigning a mathematical parameter to represent the duration (or difficulty) of a given processing component.



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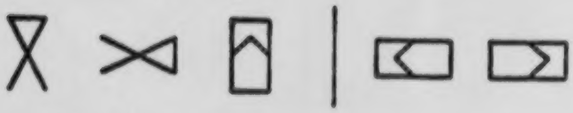

Figure 2. Examples of schematic-picture, verbal, and geometric analogies. The first two analogy types were true-false; the last was forced-choice. Subjects were told either to determine whether the analogy was true or false, or to determine which of two answer options better completed the analogy. Subjects solving schematic-picture analogies were told that found binary attributes--height (tall, short), weight (fat, thin), sex (male, female), and clothing color (blue, red, in the actual stimuli) were relevant to item solution.

Multiple linear regression was used to predict the mean response time to each analogy item type from the appropriate set of independent variables representing the number of times a given component had to be performed in analogy solution. This model-testing procedure was possible because items had been systematically constructed so as to vary the sources of difficulty involved in their solution.

Mean response times were 1.42 seconds for schematic-picture analogies, 2.42 seconds for verbal analogies, and 6.58 seconds for geometric analogies. Error rates were very low (ranging from 1-5% across tasks). The proposed theory provided the best fit to the latency data, accounting for .92, .86, and .80 of the variance in the schematic picture, verbal, and geometric group-mean latency data. (These proportions are the squared correlations [R^2] between predicted and observed data points for each of the analogy item types in each of the three data sets.) Root-mean-square deviations (RMSD's) between predicted and observed data points (measuring absolute badness of fit) were .13, .26, and 1.68 seconds for the schematic-picture, verbal, and geometric analogies respectively. The preferred model under the proposed theory was one in which the inference component was exhaustive (meaning that all encoded attributes were subjected to the inference process), but in which mapping and application were self-terminating (meaning that only a portion of the encoded attributes were subjected to the mapping and application components). It is worth noting that although the proposed theory did quite a reasonable job of accounting for variance in the latency data, the unexplained variance was statistically significant, meaning that the proposed theory is not equivalent to the "true theory." There is systematic variation that still remains to be explained.

Patterns of correlations between the global (average response time over items for a given subject) and parameter (response latency for a particular processing component) scores of the analogies tasks, on the one hand, and the psychometric tests, on the other, were mixed. The perceptual-motor psychometric tests had been included for purposes of discriminant validation, meaning that I had hoped that individuals' task scores would not be correlated with them. Significant correlations of this kind would suggest that the tachistoscopically administered analogies test was measuring perceptual-motor speed, a construct that was not of interest in the present studies. Happily, neither global task scores nor parameter scores showed any significant correlations with the perceptual-speed measures. But the psychometric reasoning tests were included for purposes of convergent validation, meaning that I had hoped that global task and appropriate parameter scores would be correlated with the reasoning measures. Although the correlations between the global task and test scores were adequate (ranging from about -.4 to -.6 across the three tasks, with negative correlations indicating that shorter task latencies were associated with greater numbers correct on the psychometric tests), the localization of the loci responsible for these correlations were disappointing. Although there were some significant correlations of reasoning-type parameters (inference, mapping, application, justification) with the test scores, most of the global correlation turned out to be localized in the correlation of the response parameter with the reasoning score! Although I proposed several possible explanations for this surprising phenomenon at the time (Sternberg, 1977b), it remained for later research to show that the result was due to several factors, namely, unreliability of the reasoning component scores in contrast to the response component score (which depressed the possible correlations one could obtain with the former type of score), and (b) confounding of metacomponential latencies (which would be expected to correlate with psychometrically measured reasoning) with the response-component latency.

Why did this confounding occur? The response component score was estimated as a regression constant in the mathematical model, meaning that it was estimated as that portion of response time that was constant across item types within a given set (schematic-picture, verbal, or geometric) of analogies. The use of this (fairly standard) procedure for estimating response component time had the unfortunate result that any component latency that was constant across item types was confounded with the response constant. In subsequent studies, my colleagues and I attempted to obtain more reliable reasoning component scores and to increase the range of item difficulty and variety in order better to isolate the response component from any other component.

Extension of theory to series completions and classifications. The modeling data described above provided good support for the proposed theory of analogical reasoning processes. But the correlational results were perplexing. The data set as a whole raised two important theoretical questions.

First, could the theory of analogical reasoning processes be extended to other kinds of inductions so as to demonstrate some generality of the theory's ability to account for information processing during inductive reasoning, in general, as well as during analogical reasoning, in particular. The theory would be of considerably greater psychological interest if its components could provide an account of more than just one kind of induction, and to the extent that the historical claim is correct that reasoning by analogy provides a paradigm for inductive thought (Reitman, 1965; Spearman, 1923), the theory should generalize.

Second, the pattern of correlation between parameters of inductive reasoning tasks and scores on psychometric tests needed to be clarified. If the proposed theory of reasoning were correct, then with sufficiently reliable task parameter estimates and psychometric test scores, and with sufficient variation in item types, parameters representing durations of reasoning components--inference, mapping, application, comparison, justification--should show statistically reliable correlations with psychometrically-measured reasoning ability, and the response parameter should not, or at best show a weak correlation.

Twenty-four Yale undergraduates were confronted with three tasks--analogies, series completions, and classifications--presented via three kinds of contents--schematic pictures, words, and geometric forms (Sternberg & Gardner, 1982, 1983). An example of each of the nine kinds of items used (3 tasks x 3 contents) is shown in Figure 3. A total of 2880 items was administered to each

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Insert Figure 3 about here

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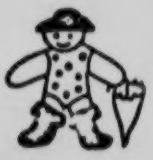
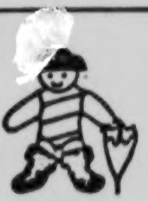
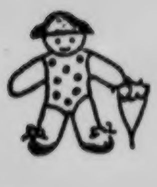
subject. This large number of items was intended to insure highly reliable global-task scores and individual parameter estimates. In addition, subjects in the experiment received two forms of each of six psychometric tests of reasoning abilities and three of perceptual-speed abilities, again to insure reliability of scores. Total testing time was about 25 hours per subject, spread out over a number of separate sessions. As in the earlier analogy experiments, the primary dependent variable was response time (with error rates as a secondary dependent variable), and independent variables were formed by manipulations of various aspects of item difficulty. Also as in the earlier experiments, task items were presented tachistoscopically, with subjects timed in their latency of response to each item.

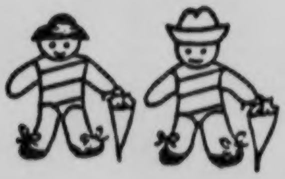
As in the analogies research, it was assumed that performance components were executed sequentially, and that these components acted upon an attribute-value representation for information. Because the comparison component was being newly added to the theory, the ability of the theory to account for the latency data with the additional component was compared to the ability of the theory to account for the data without this additional component. The question of interest was whether the additional component latency--as represented by an additional parameter in the mathematical model, accounted for statistically significant and practically substantial additional amounts of variance in the data. The answer to this question proved to be affirmative, and the data presented here are for the full set of parameters used to model the full set of data points (with each group-mean item latency serving as a data point) for the nine tasks.

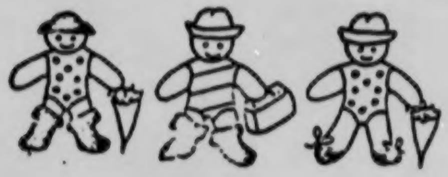
Figure 3. Examples of schematic-picture, verbal, and geometric analogies, series completions, and classifications. All items were forced choice. In the analogies, subjects had to choose the final term that was related to the third term in the same way that the second term was related to the first term. In the series completions, subjects had to choose the final term that completed the series pattern set by the first three terms as projected to the fourth term. In the classification, subjects had to decide in which of two categories (each represented by two terms) a target stimulus better fit. Subjects solving schematic-picture items were told that four binary attributes--hat color (white, black), vest pattern (striped, polka-dotted), handgear (umbrella, briefcase), and footwear (boots, shoes)--were relevant to item solution.

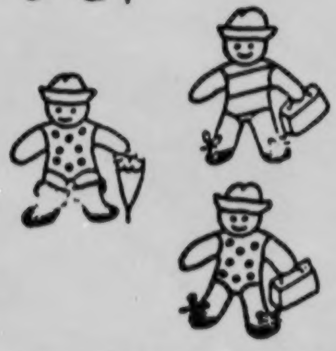


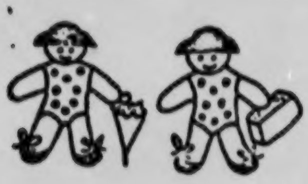


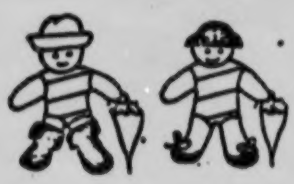


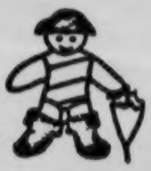












Mouth : Taste :: Eye : (a) Help (b) See

Shell : Nut :: Peel : (a) Orange (b) House

Tree : Forest :: Soldier : (a) General (b) Army

Second : Minute : Hour ::
Decade : (a) Time (b) Century

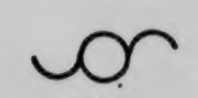
Rarely : Sometimes : Often ::
Many : (a) Frequently (b) Most

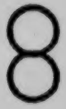
Baby carriage : Tricycle : Bicycle ::
Measles : (a) Illness (b) Acne

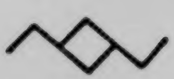
(a) Dictionary Encyclopedia (b) Lemonade Rum
Gasoline

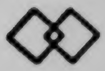
(a) Furnace Stove (b) Refrigerator Air conditioner
Oven

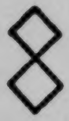
(a) Germany France (b) Vietnam Korea
Italy

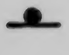


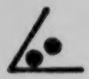


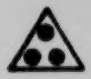


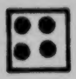


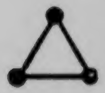


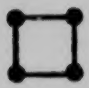


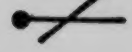


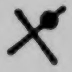


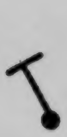












Again, mathematical modeling was accomplished by linear multiple regression.

Mean response times across the nine tasks ranged from 2.92 to 5.87 seconds, with a median of 4.50 seconds. There was only a weak effect of reasoning task, but in terms of content, geometric items were clearly more difficult than the other two kinds of items. Error rates ranged from .002 to .055 with a median of .028 across the nine tasks.

Values of R^2 (proportion of variance in the group-mean latency data accounted for) ranged over the nine tasks from .49 to .94 with a median of .67. The major variable affecting R^2 was content rather than reasoning task. In particular, values of R^2 were lower for geometric items. Median values of R^2 were .76 for schematic-picture items, .67 for verbal items, and .58 for geometric items. As was the case in the previous experiments, the unaccounted for variance was statistically significant. Values of RMSD ranged across the nine tasks from .18 second to 1.90 seconds, with a median of .71 second. We were particularly interested in these experiments in examining patterns of correlations between experimental task and psychometric test scores. Correlations for global task scores with averaged reasoning and perceptual-motor speed scores were promising. Correlations with the reasoning tests ranged from -.47 to -.72 with a median of -.64; correlations with the perceptual-motor speed tests, however, ranged only from .16 down to -.13, with a median of .00. The overall correlations thus demonstrated both convergent validity (the task scores correlated with reasoning test scores, as predicted) and discriminant validity (the task scores did not correlate with perceptual-motor speed test scores, as predicted). The correlational patterns for the component scores were also promising. A combined inference-mapping-application parameter(with the combination having been computed to increase reliability of the estimate) correlated with the combined psychometric reasoning score -.70 for analogies, -.50 for series completions, and -.64 for classifications (in each case, collapsed over the three types of contents). The comparison parameter also correlated significantly and substantially with psychometrically measured reasoning, with correlations of -.61, -.66, and -.67 for analogies, series completions, and classifications (collapsed over contents) respectively. Each of encoding and justification show mixed patterns of correlations (some statistically significant, some not). The response parameter did not correlate significantly with reasoning in any case: These correlations were -.39, -.01, and -.25 for analogies, series completions, and classifications, respectively. No parameters correlated significantly with the psychometric perceptual-motor speed scores.

These patterns of correlations were theoretically important for two reasons. First, they showed the desired pattern of convergent-discriminant validation with psychometrically-measured reasoning and perceptual-motor speed: Substantial correlations were obtained with the former but not the latter. Second, and even more importantly in view of the results of the earlier analogy experiments, convergent and discriminant validation were demonstrated in the particular pattern of correlation between the task parameters and psychometrically-measured reasoning: The reasoning parameters showed substantial correlations with psychometrically-measured reasoning, but the response parameter did not. The use of highly reliable parameters and psychometric test scores, and the use of a wide range of item difficulties, seemed to have paid off.

The above analyses concentrated upon the use of response time as a dependent measure, and assumed individuals represented information mentally in an attribute-value format. In a separate experiment, Mike Gardner and I constructed mammal-name analogies, series completions, and classifications, and used Henley's (1969) multidimensional scaling of the space of mammal names as a representational basis for predicting subjects' response choices in rank-ordering the goodness of each of four alternative answer options as completions to each item. In this scaling, mammal names are embedded in a three-dimensional space having as its dimensions size, ferocity, and humanness. A gorilla, for example, would be fairly high on all three dimensions, whereas a mouse would be fairly low. A giraffe would be high on size but low on ferocity and humanness. Examples of the items we used are shown in Table 1.

Insert Table 1 about here

Thus, we were interested here in predicting response choices rather than response times, and we assumed a multidimensional spatial mental representation rather than an attribute-value one. The theoretical basis for this work derived from the work of Rumelhart and Abrahamson (1973) on a theory of response choice in analogical reasoning. We extended this theory to series completions and classifications. The theory, which postulated an exponential decay function relating ranking of goodness of response choices to distance of these response choices from the ideal response in the three-dimensional semantic space, accounted for .97, .98, and .99 of the variance in the analogies, series completion, and classification data respectively. Thus, it appears that the kind of componential breakdown I have proposed can be applied to response choice as well as response time, and to a multidimensional spatial as well as an attribute-value representation.

Table 1

Sample Animal Names Items

Analogy

Tiger : Chimpanzee :: Wolf :

(1) Raccoon (2) Camel (3) Monkey (4) Leopard

[The subject's task is to rank-order the options in terms of their goodness as completions to the analogy.]

Series Completion

Squirrel : Chipmunk ::

(1) Raccoon (2) Horse (3) Dog (4) Camel

[The subject's task is to rank-order the options in terms of their goodness as completions to the series.]

Classification

Zebra Giraffe Goat

(1) Dog (2) Cow (3) Mouse (4) Deer

[The subject's task is to rank-order the options in terms of their goodness as members of the class formed by the three terms in the item stem.)

Extension of theory to metaphors. In comprehending and appreciating a metaphor, we conceive of something new in terms of something old. In the metaphor, "Man is a wolf," for example, the "new" term, or tenor of the metaphor, man, is seen in terms of the old term, or vehicle of the metaphor, wolf. The basis for the comparison between man and wolf, or ground of the metaphor, is left implicit.

Because the conception of something new in terms of something old forms the basis for analogical thinking as well as for metaphorical thinking, and because analogical thinking has generally been thought to comprise a broader range of mental phenomena than has metaphorical thinking, some students of metaphor have been inclined to view metaphorical understanding as a form of analogical thinking (e.g., Aristotle, 1927; Billow, 1975; Gentner, 1977; Miller, 1979; Sapir, 1977; Sternberg, Tourangeau, & Nigro, 1979; Tourangeau & Sternberg, 1981, 1982 ; Sternberg & Nigro, in press.) On this view, the metaphor "Man is a wolf" can be viewed as an implicit analogy in which some properties of man are seen as analogous to some properties of a wolf; the metaphor, "The lion is the king of beasts," can be understood as the incomplete analogy, "lion : beasts :: king : ?" (Miller, 1979).

Some theorists have proposed that to view metaphors as nothing more than abridged analogies is to miss the essence of metaphors. They propose that in metaphors there is an interaction between tenor and vehicle so that the resulting meaning of the metaphor involves a blending of the two terms (Black, 1962; Richards, 1936). Some recent studies by Malgady and Johnson (1976), Verbrugge and McCarrell (1977), and others, have supported this view. Thus, one might theorize that metaphors are often built upon a foundation of analogy, but that they involve an interaction between terms that is either minimally present or entirely absent in the base analogies.

My students and I have proposed that the above view—of metaphors as analogically based with the addition of some kind or kinds of elements of interaction--can give a good account of metaphorical comprehension and appreciation. Consider an analogy presented earlier as re-expressed in multiple-choice format: "lion : beasts :: king : (a) rulers, (b) humans." When the metaphor is expressed in this form, the theory of analogical reasoning described earlier can be directly applied to the understanding of the metaphor. The subject must encode the given terms, infer the relation of lion to beasts, map the higher-order relation that links a lion to a king, apply the previously inferred relation as mapped to the new domain to generate an ideal answer, compare this answer to each of the alternatives, justify one of the given answers as better than the other, although possibly nonideal, and respond. The theorized identity of performance components does not imply equivalence in the difficulty of the metaphor and its corresponding analogy. On the one hand, the additional verbal material contained in the metaphor increases the reading load of this presentation format; on the other hand, this additional mediating context may make the metaphor more readily comprehensible. Hence, the relative difficulties of the two presentation formats will depend upon the relative effects of increased reading load and increased mediating context.

Proportional metaphors are often presented in ways that leave at least some of the terms of the underlying analogy implicit. The "lion and king" metaphor, for example, could be presented in any of the following formats (among others), where either no terms or some terms are left implicit:

1. A lion among beasts is a kind among people.
2. A lion among beasts is a king.
3. A lion is a king among people.
4. A lion is a king.
5. A lion is a king among beasts.

An important thing to notice in these various metaphorical forms is that different terms are left implicit in different forms of presentation. These different forms may differ in their comprehensibility, as well as in their aptness, as a function of the terms that are left implicit, and, in the fifth form, as a function of the reordering of terms: "Beasts," the second term of the implicit analogy, is presented last. On the present theory, the reason for these variations in comprehensibility and information-processing difficulty would be found in the fact that these forms require not only comprehension of the explicit terms and of the relations that can be formed between these terms, but also the generation of terms that are left implicit, and the comprehension of relations between these pairs of terms (as well as between implicit and explicit ones). Miller (1979) seems to share a similar view.

The views presented above led Georgia Nigro and I to several predictions about metaphorical information processing (Sternberg & Nigro, in press). First, the information-processing components used in the understanding of metaphors and especially metaphors with relatively fewer implicit terms should be highly overlapping with the components used in the understanding of analogies. Second, metaphors should become more comprehensible and be viewed as more apt as the number of terms of the underlying analogy that are made explicit is increased, thereby clarifying the meaning of the metaphor. Third, metaphors should become more comprehensible and be viewed as more apt as tenor-vehicle interaction is made more clear and vivid by the language in which the metaphor is presented. These hypotheses were tested in two experiments.

The first experiment investigated the first hypothesis. Base statements were presented in either metaphorical or analogical form with two forced-choice options for completion of the statements. All elements in the metaphors from the underlying analogy were made explicit. Thus, a subject might see either "Bees in a hive are a Roman mob in the (a) Coliseum, (b) streets," or "Bees : Hive :: Roman mob : (a) Coliseum, (b) streets." Subjects were asked to complete the statements as quickly and as accurately as possible. Half of the 96 subjects saw the metaphorical format and half saw the analogical format. Each subject was presented with a set of 50 different test items.

Mean response latencies were 3.84 and 3.90 seconds for the metaphorical and analogical item formats, respectively. The difference between these latencies was nonsignificant. Error rates were .06 in each condition, and these, too, obviously did not differ significantly. These mean data are thus consistent with the notion that similar or identical processing components are used in each task. The correlation between latencies (computed across item types) was .80; that between error rates was not meaningful because of the very low error rates on individual item types. The correlation between latencies needs to be considered in conjunction with the internal-consistency reliabilities of the latency data, which were .90 for the metaphors and .93 for the analogies. The comparison between the task intercorrelation and the task reliabilities shows that although processing of metaphors and analogies was probably highly similar in nature, it was not identical, since there was still some systematic variance left unaccounted for. As mentioned earlier, at least some difference would be expected, since the metaphors supplied mediating context that was absent in the analogies, and may have increased tenor-vehicle interaction.

The data were mathematically modeled by predicting response latencies from the independent variables specified by the proposed theory of analogical and metaphorical reasoning. The overall fit of the model to each data set was quite good: Squared correlations (R^2) between predicted and observed latencies were .86 for the metaphors and .73 for the analogical format. Root-mean-square deviations (RMSDs) of observed from predicted values were .30 and .60 seconds in the metaphorical and analogical conditions, respectively. These model fits are based upon only the four strongest regression parameters of the proposed model. If all parameters allowed by the theory are entered in, the values of R^2 increase to .87 for metaphors and .83 for analogies. Clearly, the proposed model does a reasonable job of accounting for latency data reflecting the comprehension of both the metaphors and the analogies.

A second experiment investigated the second and third hypotheses, as well as providing additional confirming evidence for the first hypothesis. In this experiment, base statements were presented in each of the five different metaphorical formats presented earlier, where the formats differed in the number and identities of the terms of the underlying analogy that were left implicit. Subjects were asked to rate either the aptness or the comprehensibility of each metaphorical statement. Half of the 48 subjects rated aptness, the other half, comprehensibility, for each of the 50 metaphors of Experiment 1 re-presented in the five formats described earlier (e.g., (1) Bees in a hive are a Roman mob in the Coliseum; (2) Bees in a hive are a Roman mob; (3) Bees are a Roman mob in the Coliseum; (4) Bees are a Roman mob; and (5) Bees are a Roman mob in a hive).

For aptness, the effect of metaphorical form was highly significant. An examination of the pattern of ratings revealed that for Forms 1-4, higher ratings were attained for metaphorical formats in which fewer terms were left implicit, as predicted. Thus, when terms are presented in the natural A-B-C-D order corresponding to the order of terms in the implicit analogy, the presentation of more terms is associated with higher aptness. But Form 5, where the order of the second and third terms was reversed relative to the implicit underlying analogy ("Roman mob," in the example, precedes rather than follows "hive"), was rated as most apt. The high Form 5 rating did not merely reflect its intermediate number of terms. We suggest that the Form 5 metaphor was rated as most apt because the ordering of terms suggested something more than is suggested in the other metaphorical forms: In particular, it suggested an interaction between tenor and vehicle more than that suggested by the other forms. In metaphors such as "A pear is a Buddha on a sill," or "Bees are a Roman mob in a hive," or "Tombstones are teeth in a graveyard," the tenor is more easily conceived in terms of the vehicle, and it is especially easy in many cases to create an image of tenor-vehicle interaction. One can easily imagine a Buddha transplanted to a window sill, a Roman mob scurrying mindlessly in a hive, or teeth sticking up from the ground in a graveyard. The fifth form thus provides an ordering of terms that facilitates one's understanding of tenor-vehicle interaction, and thus aptness is increased. In the other metaphorical forms, adherence to the order of terms in the underlying analogy reduces ease of perceived interaction of tenor and vehicle, and aptness is correspondingly reduced. In order to test our hypothesis that the fifth metaphorical form encouraged formation of interactive imagery more than did the second metaphorical form (which contained exactly the same terms in the standard analogical order) or than did any other form, we had a separate group of 20 subjects rate vividness of interactive imagery for each metaphor in each format. Mean ratings were highest for Form 5. Most critically, the mean for Form 5 was higher than for Form 2, which differed only in order but not in content of terms. The same patterns of results obtained for aptness obtained as well for comprehensibility.

We also mathematically modeled the ratings of aptness and comprehensibility on the basis of the independent variables in our theory. For the full model plus the effect of interactive imagery plus the effect of comprehensibility on aptness or the effect of aptness on comprehensibility, values of R^2 between predicted and observed data for the five respective metaphorical formats were .71, .77, .69, .78, and .71 for aptness, and .78, .80, .73, .86, and .82 for comprehensibility. These model fits were quite impressive in view of the fact that the theory was originally formulated to predict response latencies rather than ratings of aptness or comprehensibility.

The results of the second experiment thus confirmed our second and third hypotheses, as well as providing additional confirming evidence for our first hypothesis. The componential theory of analogical reasoning seems to lend itself to extension to metaphorical comprehension, as well as to metaphorical aptness and comprehensibility as measured by subjects' ratings.

The research described above emphasized processing of metaphorical information. Roger Tourangeau and I have concentrated upon the representation of metaphorical information in a separate series of studies (Tourangeau & Sternberg, 1981, 1982). Imagine an array of "local subspaces" comprising sets of terms, such as U.S. historical figures, modern world leaders, mammals, birds, fish, airplanes, land vehicles, and ships. Each local subspace represents the terms within it as points with coordinates on each of several dimensions. Each of these local subspaces might also be viewed as of roughly the same order (level of abstraction), and as of a lower order than a higher-order hyperspace that contains the lower-order subspaces as points embedded within it. Thus, the points of the higher-order hyperspace map into the lower-order subspaces, and can be labeled by the names of these subspaces. This hyperspace can, in turn, be viewed as one of multiple subspaces of some still higher-order hyperspace, although such very high-order hyperspaces will not concern us here.

We shall also need some rule for restricting the subspaces that map into a single hyperspace, and some way of establishing comparability across subspaces. Both of these goals can be accomplished by requiring all subspaces to have at least one corresponding dimension. Thus, for example, the subspaces of modern world leaders, bird names, and ships must have at least one corresponding dimension if they are to be local subspaces of the same order and of a common hyperspace.

In a semantic-differential paradigm (Osgood, Suci, & Tannenbaum, 1957), subjects were asked to rate each of twenty items within each domain on twenty-one scales, such as warlike-peaceful, noble-ignoble, and strong-weak, with a different group of sixteen subjects supplying ratings for each of the eight domains. We hoped in this way to obtain a corresponding set of dimensions for the eight domains named above (U.S. historical figures, modern world leaders, mammals, birds, fish, airplanes, land vehicles, and ships). It seemed plausible to us that at least two such corresponding dimensions would obtain: prestige (similar to Osgood et al.'s "evaluative" dimension) and aggression (similar to Osgood et al.'s "potency" or "activity" dimensions). The adjective pairs for each domain were then factor analyzed.

Visual inspection of the results of the factor analyses supported our hypothesis: Two corresponding dimensions of prestige and aggression appeared for each domain, although the order in which the two dimensions appeared was variable across domains. In order to confirm our visual impression, statistical analyses were performed to ascertain degrees of dimensional interrelatedness. Corresponding dimensions according to the visual analysis were found to be highly statistically related as well, and noncorresponding dimensions to be only poorly statistically related.

This representational framework was used as a basis for constructing rules that would identify metaphors as more or less aesthetically pleasing. Two distances in the proposed spaces were deemed relevant: "superimposed within-subspace distance" between the tenor (first term) of the metaphor and the vehicle (second term) of the metaphor, and "between-subspace distance" between these two terms.

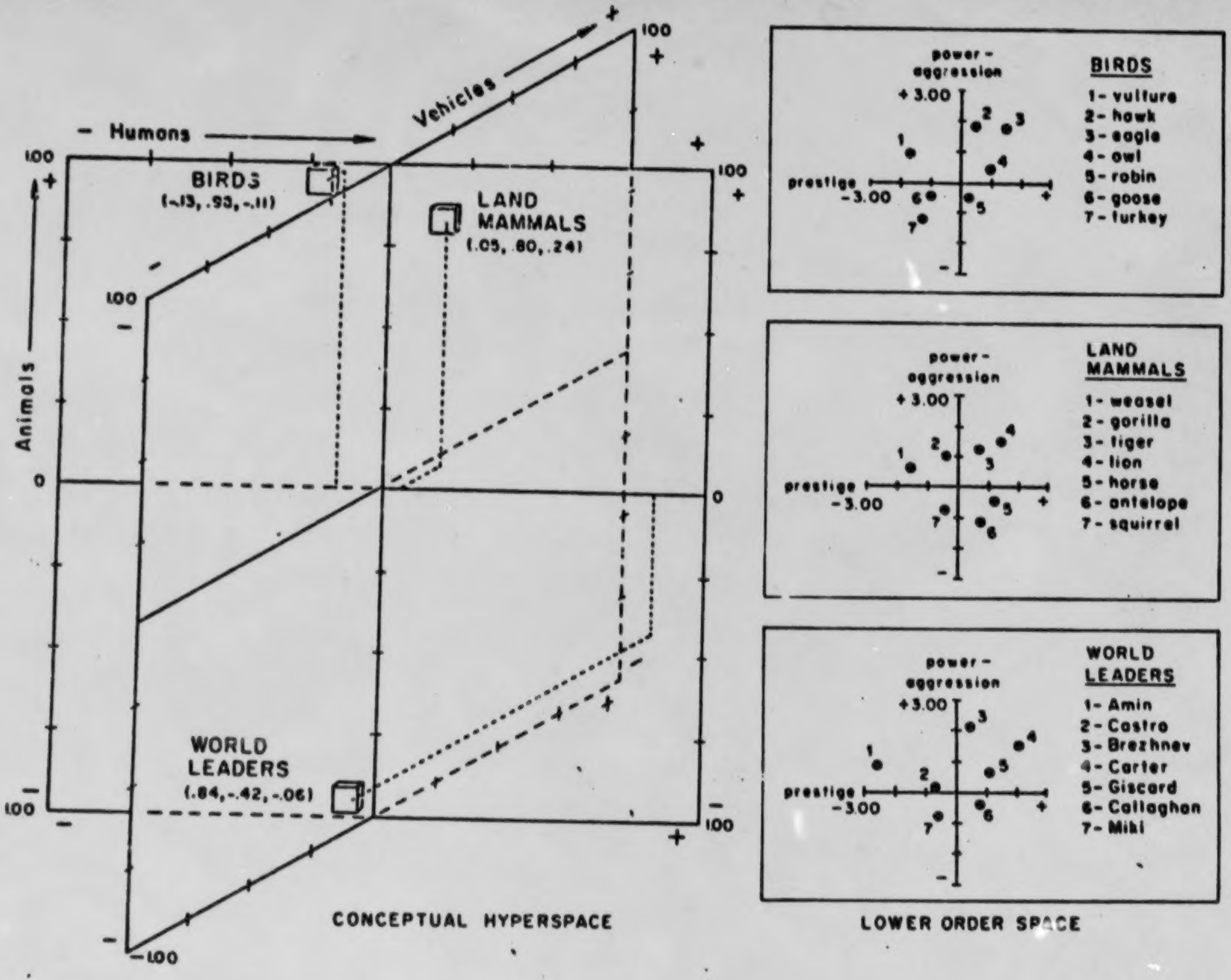
Consider first the meaning of "superimposed within-subspace distance." Since at least two dimensions are corresponding (or at least, very similar) for each domain, one can imagine superimposing the dimensions of one local subspace onto the corresponding dimensions of another local subspace. Once this superimposition is accomplished, it is also possible to imagine computing the superimposed within-subspace distance between two points that are actually in different subspaces. One simply computes the distance between points as though they were in the same subspace. Thus, if the coordinates of some point in one subspace were (x, y), then the superimposed within-subspace distance to some point in another subspace would be 0 if that point also happened to occupy location (x, y), and would depart from 0 as the Euclidean distance of that point from (x, y) increased.

An example may help clarify the concept. The superimposed within-subspace distance from wildcat to hawk is very small, because the coordinates of hawk in the bird subspace are very close to those of wildcat in the mammal subspace. The superimposed within-subspace distance from wildcat to robin is quite large, however, because the coordinates of wildcat and robin are quite disparate. Similarly, the superimposed within-subspace distance from wildcat to ICBM is small, whereas the superimposed within-subspace distance from wildcat to blimp is large. The distance concept is further illustrated in Figure 4.

Insert Figure 4 about here

Consider next the meaning of "between-subspace" distance. In order for the concept to have meaning, it must be possible somehow to compute the distance between a pair of subspaces. This computation is possible, in our representational formulation, because the distance between two subspaces is equal to the distance between the corresponding points within the appropriate hyperspace. Thus, if the coordinates of some local subspace in the hyperspace are (x, y), the distance from that subspace to another subspace increases as the Euclidean distance of that subspace from (x, y) increases.

Let us return to our earlier example to illustrate the concept of between-subspace distance. The between-subspace distance from wildcat to hawk is the same



Humans
Vehicles
Animals
BIRDS
(-.13, .93, -.11)
LAND
MAMMALS
(.05, .80, .24)
WORLD
LEADERS
(.84, -.42, -.06)
100
1.00
0
-1.00
+
-
CONCEPTUAL HYPERSPACE
power-aggression
+3.00
prestige
-3.00
BIRDS
1- vulture
2- hawk
3- eagle
4- owl
5- robin
6- goose
7- turkey
LAND MAMMALS
1- weasel
2- gorilla
3- tiger
4- lion
5- horse
6- antelope
7- squirrel
WORLD LEADERS
1- Amin
2- Castro
3- Brezhnev
4- Carter
5- Giscard
6- Callaghan
7- Miki
LOWER ORDER SPACE

Figure 4. Illustration of a hyperspace and three local subspaces.

as that from wildcat to robin, since both hawk and robin are in the same local subspace. This distance is small, since mammal and bird names are viewed as relatively close to one another in the hyperspace. The between-subspace distances from wildcat to ICBM and blimp are also the same, since these latter two terms fall within the same local subspace; and this distance is relatively large, since mammal names and names of airplanes are viewed as relatively far from one another in the hyperspace. The distance concept is illustrated further in Figure 4.

Turning now to the theory of metaphorical aptness, we proposed that a metaphor is aesthetically pleasing, or apt, to the extent that the superimposed within-subspace distance is small, but the between-subspace distance is large. Consider some examples of metaphors derived from the terms discussed above: (1) A wildcat is a hawk among mammals; (2) A wildcat is a robin among mammals; (3) A wildcat is an ICBM among mammals; and (4) A wildcat is a blimp among mammals. What empirical claims does the proposed theory make about each of these metaphors? According to the theory, (3) should be the metaphor of highest quality, since although wildcat and ICBM are quite close to one another in terms of superimposed within-subspace distance, they are from distant local subspaces. Metaphor (2) should be lowest in quality, because the tenor and vehicle occupy discrepant positions in their respective subspaces, and are from proximal subspaces. Metaphors (1) and (4) should be intermediate in quality. Since we expect superimposed within-subspace distance to carry more weight than between-subspace distance, we would predict that metaphor (1) would be perceived as more apt than metaphor (4). Thus, the ordering of metaphors in terms of aptness is, from greatest to least, (3), (1), (4), (2).

The predictions of our "dual-distance" theory were tested in two experiments. In Experiment 1, 37 subjects were asked to rate the aptness of metaphors such as "The owl is the horse among birds." Tenors and vehicles were taken from the local subspaces described earlier. According to our theory, metaphorical aptness should be negatively correlated with the superimposed within-subspace distance between tenor and vehicle, and positively correlated with the between-subspace distance. Both predictions were confirmed. Correlations were -.39 for superimposed within-subspace distance, and .27 for between-subspace distance (both statistically significant, if small). When multiple regression was used to predict aptness from these two distances plus comprehensibility of the metaphor, the multiple correlation was .76. A fact of incidental interest is that the simple correlation of overall distance with metaphorical goodness was just -.01. This trivial correlation suggests why many previous investigations that have failed to make our distinction between the two kinds of distances have been inconclusive and theoretically inadequate.

In Experiment 2, 20 subjects were asked to rank-order the goodness of metaphorical completions in terms with the format exemplified by "A crab is a _____ among sea creatures. (1) tiger, (2) mongoose, (3) rat, (4) horse." Half the items had options chosen from a single local subspace, as in the example, and half had options chosen from multiple local subspaces, for example, "A blue whale is a _____ among sea creatures. (1) killer whale, (2) Giscard d'Estaing, (3) satellite, (4) lion." The rank-order correlation between superimposed within-subspace distance and option popularity (aptness) was -.46 for metaphors of the first kind (options from a single local subspace) and -.48 for metaphors of the second kind (options from multiple local subspaces). The correlation with between-subspace distance, which could be computed only for metaphors of the second kind, was a nonsignificant .06. An exponential model was also fit to the response-choice data, with choice proportions predicted on the basis of the two kinds of distances. The model was successful for the options of the first kind (correlation between predicted and observed values equal to .98) but not for the options of the second kind, where between- as well as superimposed within-subspace distance was manipulated.

Although the theory was applied only to items falling within semantic fields, its general principles can be applied to items outside such fields. For example, the theory predicts that Donne's famous conceit relating lovers to stiff twin compasses will be apt because the superimposed within-subspace distance, as shown by Donne, is low (i.e., lovers and stiff twin compasses can be shown to bear many similarities), but the between-subspace distance is high (i.e., lovers and stiff twin compasses are from very distant domains). At the opposite extreme, literal statements make for poor metaphors because their between-subspace distance is zero, regardless of what their within-subspace distance may be. For example, "An ICBM is an intercontinental missile" has zero superimposed within-subspace distance (which is good for metaphorical aptness), but zero between-subspace distance as well (which is bad for metaphorical aptness). Anomalous statements such as "An ICBM is a haystack" make for poor metaphors because whatever may be their between-subspace distance, their superimposed within-subspace distance will generally be very high.

To conclude, we have proposed theories of metaphorical information processing and representation that seem to capture major aspects of metaphorical comprehension and appreciation. The theory suggests that metaphorical processing can be related to other kinds of inductive information processing in terms of the components used in metaphorical understanding, but that an additional element, that of interaction, applies uniquely to the metaphorical (or figurative) format of verbal presentation.

Theory of causal inference. Civilian and military personnel alike frequently need to infer the causal antecedent or antecedents of significant real-world events. For example, the response of the United States government to the recent Soviet invasion of Afghanistan was predicated upon the motives U.S. government officials inferred to underlie the Soviet attack. The response would almost certainly have been different if government policy-makers had believed Soviet claims that the Soviets were merely responding to a request from the Afghan government for help in resolving domestic turmoil.

We have proposed that people use four basic kinds of evidence in evaluating the likelihood that a given event is a causal antecedent for a given consequent (Schustack & Sternberg, 1981; Sternberg & Schustack, 1981):

1. Confirmation by joint presence of possibly causal event and outcome. The potential cause and the given outcome tend to occur in conjunction. For example, because widespread increases in wages tend to be followed by widespread increases in prices, we tend to attribute the price increases at least in part to the increases in wages (the well-known "inflationary spiral"). This relation between the possibly causal event and the outcome event is evidence in favor of the sufficiency of the possibly causal event for the outcome, i.e., if the possibly causal event occurs, so does the outcome.

2. Confirmation by joint absence of possibly causal event and outcome. The absence of the potential cause tends to be associated with the absence of the given outcome. For example, countries that are disarmed (or almost disarmed) tend not to start wars, so that one might reasonably conclude that the starting of wars is at least in part attributable to the presence of armaments in a country's arsenal. This relation between the possibly causal event and the outcome event is evidence in favor of the necessity of the possibly causal event for the outcome, i.e., the outcome event (here, starting wars) tends to occur only if the antecedent event is present (here, armaments in the country's arsenal).

3. Disconfirmation by presence of possibly causal event but absence of outcome. The presence of the potential cause tends to be associated with the absence of the given outcome. For example, the presence of large numbers of members of a given ethnic group in a country originally foreign to them does not (usually!) lead to overt action on the part of these ethnics to take over the country by force. This relation between the possibly causal event and the outcome event is evidence against the sufficiency of the possibly causal event for the outcome, that is, the occurrence of the possibly causal event does not always lead to the occurrence of the outcome. Thus, in our country, there are large ethnic populations, but such populations have not been associated with attempts to overthrow the government.

4. Disconfirmation by absence of possibly causal event but presence of outcome. The absence of the potential cause tends to be associated with the presence of the given outcome. For example, a suspect's having been a hundred miles away from the scene of a murder at the time the murder occurred would tend to disconfirm the inference that the suspect committed the crime. This relation is evidence against the necessity of the possibly causal event for the outcome, i.e., the occurrence of the outcome (the crime in this example) was not preceded by the occurrence of the possibly causal event (the suspect's having been present).

A fifth kind of information can also be relevant to causal inferences, namely, base rate. Base rate refers to the probability of a given outcome occurring in the absence of any new information regarding the probability of occurrence in the particular situation. One simply uses one's world knowledge about cooccurrences of events. We theorized, in concordance with past literature (e.g., Nisbett & Ross, 1980), that base-rate information is used only minimally in causal inference.

It is important to note that the kinds of information considered above can be used both to test one's preferred hypothesis, and to test alternative hypotheses as well. Thus, the various kinds of evidence can be combined to give a causal likelihood for each of a set of potential causal antecedents.

In our research on causal inference, subjects had to evaluate the likelihood that a given outcome event was the result of a particular hypothesized causal event. Individuals had to make these judgments with incomplete information about complex problems varying simultaneously on many dimensions. In making the judgments, subjects had to decide what kinds of evidence to consider, how to weight each kind of evidence, how to combine various kinds of evidence, and how to translate their conclusions into a probability that the target hypothesis was responsible for the target outcome.

The problems used in our research resembled in many respects problems encountered in real-world settings that require causal inferences. We used three basic kinds of problems that differed in the content domain in which the causal inference was to be made: (a) an epidemiological domain, in which the individual had to judge the likelihood that a particular hazard was responsible for a given epidemic; (b) a securities domain, in which the individual had to judge the likelihood that a particular circumstance was responsible for a precipitous decline in the value of a company stock; and (c) an abstract domain, in which the individual had to judge the likelihood that a particular circumstance (labeled only by a letter) was responsible for some other particular circumstance (also labeled only by a letter). Consider a sample problem from the securities domain:

A market analyst noted that, among pharmaceutical manufacturers:

In Company 1,

The office staff of the company organized and joined a union.
The company's major product was under suspicion as a carcinogen.

There was a drastic drop in the value of the company's stock.

In Company 2,

The office staff of the company did not organize or join a union.
The company's major product was under suspicion as a carcinogen.

There was a drastic drop in the value of the company's stock.

In Company 3,

Illegal campaign contributions were traced to the company's managers.

The company's major product was not under suspicion as a carcinogen.

There was not a drastic drop in the value of the company's stock.

WHAT IS THE PROBABILITY THAT, FOR SOME OTHER PHARMACEUTICAL MANUFACTURER, STOCK VALUES WOULD DROP DRASTICALLY IF THE COMPANY'S MAJOR PRODUCT WERE UNDER SUSPICION AS A CARCINOGEN?

In each problem of each kind, individuals were presented with the hypothesis that a particular event was responsible for some outcome. They were asked to use a given body of evidence to estimate the probability (placed on a 0-100 scale to eliminate decimal points) with which that event, by itself, would produce that outcome. Individuals were explicitly warned that they were being given incomplete information and that interactions between possibly causal events were possible; these warning were aimed at evoking the same kind of mental set as would real-life causal inference.

Within any situation in any kind of problem, each possible cause was in one of three states: observed to be present (e.g., "The office staff of the company organized and joined a union"), observed to be absent (e.g., "The office staff of the company did not organize or join a union"), or not observed (e.g., nothing is stated about unionization). Over the set of problems in three content domains, there were from two to five situations (cities, companies, or lines of problems) described in a single problem, and also from two to five possibly causal events observed per situation independently of the number of situations. Within a single problem, each situation had the same number of observed possibly-causal events.

Sixty-two subjects supplied probability ratings for each of the two concrete content domains, with order of domain counterbalanced. Forty subjects supplied probability ratings for the abstract content domain only. An additional 21 subjects supplied base-rate ratings for the concrete-content domain. These subjects were asked the question without being given the prior information about the companies (epidemics, or abstract letters). Other experiments used similar designs (see Schustack & Sternberg, 1981, for a full description of the complete set of experiments, only one of which is described here), with similar results.

Mean response probabilities were .35 for epidemics, .37 for securities, and .35 for abstract items (with decimal points now inserted for ease of comprehension). The means did not differ significantly from each other. Values of R^2 between predicted and observed probabilities were .90, .88, and .90 for epidemics, securities, and abstract content respectively. Deviations from the model were statistically significant, despite the high levels of fit. RMSD's of observed from predicted values were .07, .06, and .06 (with decimal points again inserted by us) for the three respective content types. The proposed theory of causal inference was tested against a number of plausible alternative theories, and was found to provide a superior account of the data. These alternatives included both linear and nonlinear models.

It is worth noting that parameter estimates for the four kinds of evidence considered by the theory were highly similar across the three content domains. Consistent with past evidence in research on causal inference (e.g., Wason, 1960), people weighted positive confirming evidence the most highly. Also consistent with past evidence, base rate information was hardly used at all. Evidence about hypotheses alternative to the one being considered was evaluated, but was assigned much less weight than would have been optimal. On the whole, we found that people used a wide variety of evidence types in making their judgments, but the weights they assigned these types of information were rather far from those that would be assigned if all types got equal weight.There were relatively small individual differences in these weights, but weight values for individual subjects were not correlated with scores on standard IQ tests, nor is there any a priori reason to expect they ought to be: We are dealing with problems in which no one set of weights would most clearly be associated with high intelligence.

Theory of projection in a nonentrenched reasoning task. During the past several years, I have been pursuing the notion that intelligence is in large part the ability to acquire and reason with new conceptual systems. It is not merely the ability to learn and reason with new concepts but the ability to learn and reason with new kinds of concepts. Intelligence is not so much a person's ability to learn or think within conceptual systems that the person has already become familiar with as it is his or her ability to learn and think within new conceptual systems, which can then be brought to bear upon existing knowledge structures. Thus, an intelligent person must first learn a new conceptual system and then see how it applies (analogically) to old problems. I have referred to tasks requiring novel kinds of thinking in novel domains as "nonentrenched."

The main nonentrenched task I have studied is one that requires the individual to make a projection that characterizes the state of an object at some future time on the basis of incomplete information about the state of the object both at that time and at some earlier time. The projection task was studied with three different "surface" structures having very similar "deep" structures. Consider the first instantiation of the task, which requires projection of the color an object will appear to be at a future time.

In the first instantiation of the task, subjects were presented with a description of the color of an object in the present day and in the year 2000. The description could be either physical--a green dot or a blue dot--or verbal--one of four color words, namely, *green*, *blue*, *grue*, and *bleen*. An object was defined as green if it appeared physically green both in the present and in the year 2000. An object was defined as blue if it appeared physically blue both in the present and in the year 2000. An object was defined as grue if it appeared physically green in the present but physically blue in the year 2000 (i.e., it appeared physically green until the year 2000 and physically blue thereafter). An object was defined as bleen if it appeared physically blue in the present but physically green in the year 2000 (i.e., it appeared physically blue until the year 2000 and physically green thereafter). (The terminology is based upon Goodman, 1955.)

Since each of the two descriptions (one in the present and one in the year 2000) could take one of either two physical forms or four verbal forms, there were 36 (6 x 6) different item types. The subject's task was to describe the object in the year 2000. If the given description for the year 2000 was a physical one, the subject had to indicate the correct verbal description of the object; if the given description for the year 2000 was a verbal one, the subject had to indicate the correct physical description of the object. There were always three answer choices from which the subject had to choose the correct one.

Subjects were alerted to a complexity in the projection task that applies to the real world as well. When one observes the physical appearance of an object in the present day, one can be certain of its current physical appearance but not of what its physical appearance will be in the year 2000. Hence, all descriptions presented for the present day could be guaranteed to be accurate with respect to physical appearance in the present, but they could not be guaranteed to be accurate with respect to their implications, if any, regarding physical appearance in the future. For physical descriptions of objects as they appear in the present, this complexity presents no problems, since the physical description of an object (a green dot or a blue dot) carries no implications regarding the future physical appearance of the object. For verbal descriptions of objects as they appear in the present, however, this complexity does present a problem. The verbal descriptions green and blue imply constancy in physical appearance, whereas the verbal descriptions grue and bleen imply change. Unfortunately, all one can infer with certainty from these verbal descriptions is the current physical appearance of the object. The implication for the future physical appearance of the object can only be a guess, which may be right or wrong. This complexity ceases to exist for the observer in the year 2000 because at this point all of the evidence is in. The observer in the year 2000 knows for certain what the physical appearance of the object is in 2000 and also knows for certain what the physical appearance of the object was in what was once the present. Hence, the second description, that of the object in the year 2000, is guaranteed to be correct both with respect to the object's appearance in 2000 and the object's appearance in what was once the present. (The one exception to this guarantee is a certain problem referred to as "inconsistent," as described below.)

To summarize, physical descriptions, which carried no implications for what an object would look like at another time, were always accurate in all respects. Verbal descriptions, which did carry an implication for the appearance of an object at another time, were always accurate with respect to the physical description they implied for the object at the time at which the description was given (except for inconsistent items), but in the present, they might not be accurate with respect to the physical description they implied for the year 2000.

Some examples of actual items will illustrate a few item types. (See Sternberg, 1981b, 1982, for further examples.) In these examples, the letters G and B are used to represent the colored dots (green or blue) that were used to represent physical appearances in the actual stimulus items. The letter I stands for "inconsistent." Recall that items could consist of either two verbal descriptions, a physical description and a verbal description, a verbal description and a physical description, or two physical descriptions.

Blue Blue G B I

In this example, an object is described verbally as blue in the present and as blue in 2000. Clearly, its physical appearance in 2000 is B. This was an easy item, with a mean response latency of 1.5 second.

Blue Green I B G

In this example, an object is described verbally as blue in the present but as green in 2000. These two items of information are inconsistent with each other, and hence the correct answer is the letter I. If the physical appearance of the object changes from blue in the present to green in 2000, the appropriate verbal description of the object in the year 2000 is bleen. If the physical appearance of the object does not change, the appropriate verbal description in the year 2000 is blue. But an object cannot correctly be described as green in the year 2000 if its physical appearance was formerly blue. This item was moderately difficult, with a mean response latency of 2.5 seconds.

G Grue G B I

In this example, an object is described as physically green in the present but as verbally grue in the year 2000. The object thus must have appeared physically green in the present and physically blue in 2000. The correct answer is B. This item was also moderately difficult, with a mean solution latency of 3.1 seconds.

Bleen B Green Bleen Blue

In this example, an object is described verbally as bleen in the present and physically as B in 2000. One can infer that its physical appearance remained in 2000 what it was in the present, blue. The prediction that the object would change in physical appearance was incorrect. The correct answer is blue. This was a very difficult item, with a mean solution latency of 4.3 seconds.

B G Bleen Green Grue

In this example, an object is described physically as B in the present and as G in 2000. The correct verbal description of the object in 2000 is bleen. This was a difficult item, with a mean solution latency of 3.5 seconds.

Consider the second instantiation of the projection task, which was seen by subjects different from those participating in the first experiment (instantiation). In this experiment, based on appearances of objects on the planet Kyron, an object was described as plin if it appears solid north of the equator and solid south of the equator, as kwef if it appears liquid north of the equator but solid south of the equator, as balt if it appears solid north of the equator but liquid south of the equator, and as pros if it appears liquid north of the equator but solid south of the equator. In each case, subjects were told that knowledge about the object was obtained first regarding its state north of the equator and then regarding its state south of the equator. Hence, "north of the equator" corresponds to "the present" in the first experiment, and "south of the equator" corresponds to "the year 2000" in the first experiment. Physical representations of objects were either a filled dot (for solid physical appearance) or a hollow dot (for liquid physical appearance). Two experiments were conducted with this instantiation.

In the third instantiation of the projection task, which was seen by still different subjects, the same four new words were again used, but their meanings were different. Four types of persons were alleged to live on the planet Kyron. A person was described as plin if the person was born a child and remained a child throughout his or her life span. A person was described as kwef if the person was born an adult and remained an adult during the course of his or her life span. A person was described as balt if the person was born a child but became an adult during the course of his or her life span. And a person was described as pros if the person was born an adult but became a child during the course of his or her life span. A stick picture of a little person was used for the physical representation of a child; a stick picture of a big person was used for the physical representation of an adult.

Each of approximately 25 subjects was tested in each of four experiments.

Testing consisted of a number of projection-task items followed by standardized tests of inductive reasoning ability from widely used tests of general intelligence. Each subject in each experiment saw each of the 36 item types three times, once with the correct answer in each of the three possible ordinal positions.

Mean latencies were 3.02 seconds for the green-blue task, 5.44 and 3.89 seconds for harder and simpler versions of the liquid-solid task, and 4.15 seconds for the child-adult task. These means differed significantly. Latencies were highly correlated across experiments (using item types as observations), suggesting similar information processing in all three instantiations. An information-processing model of task performance accounted for .94, .92, .91, and .93 of the variance (R^2) in the green-blue, liquid-solid (two versions), and child-adult task, respectively. RMSDs for the respective tasks were .20, .43, .30, and .28 seconds. Residuals were significant only in one variant of the second (liquid-solid task), indicating that the model did an exceptionally good job of accounting for the task latencies.

The most interesting results in this experiment were correlations of global task and parameter latencies with scores on the inductive-reasoning items from the IQ tests. Global correlations of task scores with psychometrically-derived scores were -.69, -.77, -.61, and -.48 for the four respective experiments. These correlations are not only consistently high and significant, but they are obviously higher than those obtained for any of the other cognitive tasks currently being studied by investigators of intelligence in their laboratories. The correlations are thus consistent with the notion that performance on nonentrenched tasks is related to intelligence in a particularly central way. Moreover, patterns of correlations of parameter scores with the psychometric scores made good sense. Parameters representing complex conceptual transformations were the ones that tended to be responsible for the higher levels of correlation, whereas parameters representing simpler operations were only trivially correlated with psychometric test scores. Thus, the componential decomposition of task performance enabled me to extract those components of information processing that were critical to "nonentrenched" reasoning.

Obviously, the situations used in this task were highly artificial. This is something that I plan to remedy in future research, using situations such as changes of colors of leaves. But the critical finding is that the abilities required to perform nonentrenched tasks successfully and to process nonentrenched concepts within such tasks appear to be consequential to measuring individual differences in intelligence. These experiments must therefore be seen as a first-pass at this kind of measurement in an artificial task environment, with more realistic task environments to follow. Certainly, the results of both the modeling and the correlations hold promise for further exploration of the concept of nonentrenchment in intelligent performance.

Summary. To summarize, I have presented a componential theory of analogical reasoning processes and shown how it can be generalized to other kinds of induction problems, namely, series completions, classifications, and metaphors. I have also presented theories of response choice in causal inference and of projection of nonentrenched events. In the next section, I consider the nature of fluid abilities that are deductive rather than inductive in nature.

Fluid Abilities: Deduction

Our investigations of fluid abilities of deductive reasoning have led us to investigations of variants of three types of syllogisms: linear syllogisms (Sternberg, 1980a, 1980b, 1980c; Sternberg & Weil, 1980), and categorical and conditional syllogisms (Guyote & Sternberg, 1981; Sternberg & Turner, 1981). Examples of the various kinds of syllogisms my collaborators and I have studied are shown in Table 2. Consider first the solution of linear syllogisms and next the solution of categorical and conditional syllogisms. Solution of the latter two kinds of syllogisms can be accounted for by a single theory, but a theory different from that accounting for the solution of linear syllogisms. Because the number and complexity of the performance components used to solve deduction problems are greater than for induction problems, the theories will be described only in outline. Details are contained in the original papers.

Insert Table 2 about here

Linear syllogisms. The proposed theory of linear syllogistic reasoning processes attempts to account for linear syllogistic reasoning in terms of the operation of eight distinguishable performance components. These components are (a) encoding, which includes time to read the premises and to combine them into a spatial array; (b) negation, including incremental time to understand negated propositions (over time required to understand affirmative propositions); (c) marking, including incremental time to understand marked adjectives such as shorter, worse, and slower (over time required to understand unmarked adjectives such as taller, better, and faster); (d) pivot search, including

Table 2

Sample Syllogisms

Linear Syllogisms

A. Sam is taller than Joe.
Joe is taller than Tom.
Who is tallest?
Joe Tom Sam

B. Sam is better than Joe.
Sam is worse than Tom.
Who is worst?
Tom Sam Joe

C. Sam is not as fast as Joe.
Tom is not as fast as Sam.
Who is slowest?
Joe Sam Tom

[The subject's task is to answer the question with one of the options.]

Categorical Syllogisms

A. No C are B.
All B are A.

All A are C.
No A are C.
Some A are C.
Some A are not C.
None of the above.

B. No cottages are skyscrapers.
All skyscrapers are buildings.

All buildings are cottages.
No buildings are cottages.
Some buildings are cottages.
Some buildings are not cottages.
None of the above.

C. No milk cartons are containers.
All containers are trash cans.

All trash cans are milk cartons.
No trash cans are milk cartons.
Some trash cans are milk cartons.
Some trash cans are not milk cartons.
None of the above.

D. No headphones are ducks.
All ducks are bottles.

All bottles are headphones.
No bottles are headphones.
Some bottles are headphones.
Some bottles are not headphones.
None of the above.

[The subject's task is to choose the logically correct option.]

Conditional Syllogism

If A then B.
Not B. /Therefore, not A.

[The subject's task is to indicate whether the syllogism is logically valid.]

time to locate the middle term of the three-item linear array inferred from the terms of the linear syllogism; (e) response search, including time to locate the correct response to the question asked in the linear syllogism; (f) noncongruence, including time to rephrase the question if it is asked in terms of an adjective different from that in which the correct answer to the question happened to be encoded (as when the correct answer is encoded in terms of "tallness" and the question asks who is "shortest;" (g) question reading, including the time to read the question posed by the linear syllogism; and (h) response, including the time to communicate one's perferred answer.

In this theory as in the theory of inductive reasoning, it is assumed that the performance components are executed in a sequential fashion. It is theorized that both linguistic and spatial forms of mental representation are used at various points in the sequence of information processing. In particular, it is theorized that the problem is first linguistically decoded such that the presented surface structure is converted to a linguistic deep structure (see Clark, 1969), and then spatially recoded, such that a spatial array is formed that represents the linear ordering of relations among the terms of the problem. Certain components are theorized to act upon the linguistic representation only (noncongruence, question reading), others upon the spatial representation only (pivot search, response search), and others upon both forms of representation (encoding, negation, marking). The response component does not act upon a representation, but merely provides a means of communication.

The proposed theory of linear syllogistic reasoning was tested against several alternative theories: a purely spatial theory (DeSoto, London, & Handel, 1965; Huttenlocher, 1968; Huttenlocher & Higgins, 1971), positing trivial linguistic processing and a set of processes acting solely upon a spatial representation for information; a purely linguistic theory (Clark, 1969) positing a set of processes acting solely upon a linguistic representation for information; a spatial to linguistic theory (Johnson-Laird, 1972; Wood, Shotter, & Godden, 1974) positing spatial processing when one first encounters linear syllogisms and linguistic processing only later after some practice, and a linguistic to spatial theory (Shaver, Pierson, & Lang, 1974) positing linguistic processing when one first encounters linear syllogisms and spatial processing only later on. The theories were compared in a number of experiments--the results of one experiment (Sternberg, 1980c, Experiment 3) will be stressed here, but the results of all of the experiments were in concordance.

Subjects in the experiment were 18 Yale undergraduates, each of whom received 288 linear syllogisms using the adjective pairs taller-shorter, better-worse, and faster-slower. The main dependent variable was response time, and independent variables were formed by manipulating aspects of item structure so as to make it possible to separate the proposed components of information processing. Items were administered tachistoscopically, and administration of the items was followed up by the administration of a series of paper-and-pencil psychometric tests of linguistic and spatial abilities.

Mean response time was 7.0 seconds with an error rate of .01. The proposed theory accounted for .84 of the variance in the group-mean latency data, with an RMSD of .38 seconds. The residual (unaccounted for) variance was statistically significant, indicating that the proposed theory was not the true one. However, the proposed theory did do a superior job of accounting for the data relative to any of the alternative theories considered. This superiority holds up across age levels from grade 3 to college (Sternberg, 1980a).

The patterns of correlation between global task and parameter scores, on the one hand, and psychometric test scores, on the other, were of particular interest in this research because they provided an additional means of distinguishing among the alternative theories. In particular, my mixture theory predicted significant correlations of global task scores with both linguistic and spatial ability test scores, the linguistic theory predicted a significant correlation only with the linguistic ability score, the spatial theory predicted a significant correlation only with the spatial ability score. The strategy-change theories predicted changing patterns of correlation with changes in level of practice. The individual theories also made specific predictions regarding patterns of correlation for specific parameter estimates with the ability scores. Correlations to be presented are for the results of four experiments combined (Sternberg, 1980c).

As it turned out, the global linear-syllogisms task score correlated significantly with both the linguistic and spatial ability test scores. The obtained correlations were -.46 and -.56 with linguistic and spatial abilities respectively. The significance and approximate levels of the correlations held up over practice, thus providing no support for the strategy-change theories. Moreover, the pattern of correlations of individual parameter estimates with the test scores was almost exactly that predicted by the mixture theory, with linguistic parameters correlating significantly with the linguistic but not with the spatial tests, spatial parameters correlating significantly with the spatial but not with the linguistic tests, mixed parameters correlating significantly with both kinds of tests, and the response parameter correlating significantly with neither kind of test.

The proposed model of linear syllogistic reasoning was originally proposed for determinate linear syllogisms, that is, ones with a uniquely determinable answer. It can be extended to indeterminate problems, however, such as "John is taller than Mary. John is taller than Susan." If one asks,"Who is tallest?" the problem is readily answerable. But if one asks, "Who is shortest?" the problem is not readily answerable, since insufficient information is given to determine whether Mary or Susan is the shorter one. By the addition of two performance components to the proposed mixture theory, the theory can handle problems of this kind. In an experiment to test the augmented theory, the theory accounted for .80 of the variance in determinate problems only, .93 of the variance in indeterminate problems only, and .89 of the variance in the two kinds of problems considered together (Sternberg, 1981c).

Testing of my proposed theory of linear syllogistic reasoning on other data sets in the literature revealed a curious finding: Although most data sets seemed to support my own theory, a few supported other theories. An experiment was performed to resolve the "curious conflicts" in the literature (Sternberg, 1980b). Eighteen adult subjects received linear syllogisms under instructions designed to yield speeds commensurate with error rates of about 10%. Latency and error data were analyzed both separately (via multiple regression) and jointly (via canonical regression). The data were also analyzed via pseudodeadlines, according to which responses were counted as correct if they were correct and fell below a given pseudodeadline and were counted as erroneous if they were incorrect or fell above a given pseudodeadline. (This procedure mimicked procedures used by others, where a genuine deadline was set for problem completion.) The analyses revealed the source of conflicts to be in the complex interrelationships between latency and error rate. In particular, the mixture theory better accounted for the data when these relationships were taken into account.

The data analyses I have presented in this article have generally sufficed to identify one theory as better than its competitors, usually in the sense that the squared correlation between that theory's predictions and the observed group-mean data is higher than the squared correlations between the predictions of alternative theories and the observed group-mean data. But such model fitting only describes the behavior of most of the people most of the time, not all of the people all of the time.

Sternberg and Weil (1980) investigated the range of variation over subjects in strategy use. They found that of 48 subjects left to their own devices regarding strategy selection, 30 employed a mixture strategy, 7 a linguistic strategy, 5 a spatial strategy, and 6 a short-cut strategy that bypassed formal reasoning processes. (Strategy use was determined by fitting each theory to each individual subject's data and by fitting the data to each theory. A subject was identified as using that strategy corresponding to the theory that best fit the individual subject's data.) To validate this individual strategy assignment further, global linear-syllogism response times were correlated with scores on linguistic and spatial ability tests. The correlational patterns were exactly as predicted. Respective correlations with linguistic and spatial ability were -.45 and -.27 in the mixture strategy group (both statistically significant), -.76 and -.28 in the linguistic-strategy group (only the former correlation statistically significant), -.08 and -.61 in the spatial-strategy group (only the latter correlation statistically significant), and -.32 and -.28 in the algorithmic strategy group (only the former correlation statistically significant, but both correlations reduced in magnitude, presumably because of the bypassing of formal reasoning).

These data show the importance of considering individual as well as group fits of theory and data in order to understand the full range of variation in human intellectual performance.

Categorical and conditional syllogisms. Our theory of categorical and conditional syllogistic reasoning (Guyote & Sternberg, 1981; Sternberg & Turner, 1981) is addressed primarily to bases for choosing responses. According to this theory and others, syllogistic reasoning can be divided into four sequential stages: encoding, combination, comparison, and response. Where theories differ is in terms of what happens in each stage. The theory is called a "transitive-chain" theory because it is theorized that syllogisms are solved by transitive inferences on premise representations.

In the encoding stage, individuals read and interpret the premises (see Table 2). According to our "transitive-chain" theory, the encoding stage is error-free, that is, subjects solving categorical and conditional syllogisms encode the premises completely and correctly. Although this is obviously a simplifying assumption, it fits our data quite well, and the addition of parameters into our theory for errors in encoding does little to change fits of the theory to the data.

In the combination stage, individuals combine encoded information in order to deduce relations between the terms presented in the major (first) and minor (second) premise of the syllogism. It is assumed that errors during the combination stage are due to limitations of working memory. In other words, individuals find that the number of possible combinations of set relations between the two premises (which can range from 1 to 16 across the full range of types of syllogisms) can exceed the capacities of their working memories to hold all these relations. We assume that individuals never process more than four possible set relations, but that they may process fewer. The probabilities of combining exactly one, two, three, and four set relations can be represented by four parameters, P1, P2, P3, and P4 respectively.

An example may help concretize the nature of the combination process. Consider the sample syllogism of Table 2, "No C are B. All B are A." The premise, "No C are B," can be represented in only one way, as nonintersecting sets. The premise, "All B are A" can be represented in two ways, as completely coincident sets, A identical to B, and as B functioning as a subset of A. There are thus 1 x 2 = 2 ways of combining the premises in this particular problem. A problem with the fewest possible combinatorial possibilities is "No C are B. No B are A," which yields 1 x 1 = 1 possible combination of set relations. A problem with the most possible combinatorial possibilities is "Some B are C. Some A are B," which yields 4 x 4 = 16 possible combinations of set relations.

In the comparison stage, individuals compare the mental results of their combination process to the presented answer options among which they will have to choose. Errors are theorized to be attributable to three causes. One cause is a bias toward selecting a conclusion whose atmosphere matches the atmosphere of the premises, where atmosphere is defined as negative if there is at least one negated premise (e.g., No B are C) and as particular if there is at least one particular premise (e.g., Some B are C). A second cause is a bias toward conclusions both that match the atmosphere of the premises and that are more restrictive in their claims (e.g., All is more restrictive than Some). A third cause is a response bias toward deciding a problem is indeterminate (i.e., no conclusion follows) when mental representations of the premise information do not match in certain respects (see Guyote & Sternberg, 1981).

In the response stage, individuals are theorized merely to communicate their proposed response. This stage is assumed to be error-free. To the extent that individuals occasionally push the wrong button or unintentionally mark an answer other than the selected one, the predictors of the model will be in error.

The theory of response choice is a nonadditive model, although it was assumed that the corresponding processing components contributing to response latency were executed in a sequential fashion. Our proposed representation of information and the proposed rules for integrating information would require more space to explain adequately than is available here (but see Guyote & Sternberg, 1981). Basically, individuals are assumed to translate relations between terms in the syllogistic premises into a propositional form, and then to combine information in the premises according to two simple rules. The derived propositional information from the combination stage is compared against propositional information inherent in the answer options in order to select a response.

Subjects in our experiments were Yale undergraduates. They received a variety of kinds of categorical and conditional syllogisms, as shown in the examples of Table 2. Not only did item formats differ, but item contents in one experiment differed as well, including syllogisms with factual, counterfactual, and anomalous premises. In the other experiments, abstract content (letters of the alphabet) was used in the premises. Both response choices and response times served as primary dependent variable. Independent variables were various aspects of item structure experimentally manipulated to permit isolation of the various performance components of syllogistic reasoning. Subjects were tested either via a computer terminal, a tachistoscope, or a booklet (paper-and-pencil). Following the experimental task, subjects in some of the experiments received psychometric tests of linguistic and spatial abilities.

Data from Guyote and Sternberg (1981) (categorical syllogisms with abstract premises, such as the first example), provide good support for the proposed theory. The mean response time was 39.5 seconds for categorical syllogisms with abstract content and the mean error rate was .43. The response-choice theory accounted for .97 of the variance in the response-choice data, with an RMSD of .05. The residual variance was statistically significant, despite the very high value of R^2. The theory accounted for .88 of the variance in the response-time data, with an RMSD of .29 second. Again, the residual variance was statistically significant.

The model also fared quite well in accounting for the data for conditional syllogisms with abstract content in the premises, for example, "If A then B. A. Is B a valid conclusion?" The mean response time for syllogisms of this kind was 13.5 seconds, and the mean error rate was .17. The proposed theory accounted for .95 of the variance in the data with an RMSD of .10. Again, the residual variance was statistically significant. For response time, the theory accounted for .84 of the variance in the data, with an RMSD of .29 second. The residual variance was significant.

Where possible, the predictions of an alternative theory, that of Erickson (1974, 1978), were compared to the predictors of our own theory. This theory differs from our own positing in that errors in syllogistic reasoning are due to incomplete information processing in each of the encoding, combination, and comparison stages of syllogistic reasoning.

The response biases built into our theory do not appear in Erickson's theory. For those experiments where comparison of the two theories was possible (Erickson's theory has been applied only to response-choice data for categorical syllogisms with two statement premises), our transitive-chain theory better accounted for the data.

Proportion correct scores on the syllogistic reasoning task were correlated with scores on the psychometric ability tests. Significant correlations were obtained with spatial ability scores (.42 and .54 for categorical and conditional syllogisms, respectively). It thus appears that the major source of individual differences in categorical and conditional syllogisms is in operation upon a spatial rather than upon a linguistic mental representation. Since the components of the combination stage represent limitations in operations upon a mental representation in working memory, whereas the components of the comparison stage merely represent response biases, one might expect the source of the obtained correlations to be localized in the combination stage. This was in fact the case.

Summary. To summarize, I have presented two componential theories of deductive reasoning--a mixture theory of linear syllogistic reasoning and a transitive-chain theory of categorical and conditional syllogistic reasoning. Two different theories were required because the information-processing requirements of categorical and conditional syllogisms differ considerably from the information-processing requirements of linear syllogisms. Nevertheless, the theories have certain communalities, most notably, the solution of problems by transitive inferences. Another important communality is the importance of a spatial mental representation in both kinds of syllogistic reasoning. Our theories predict an important role for linguistic information processing as well, but this prediction was supported only for the linear syllogisms. Overall, the high levels of fit of the theories to data provide good support for the proposed theories of information processing.

Conclusions

I have presented a componential view of human intelligence whereby intelligence is understood in terms of the functioning of various kinds of information-processing components, and in terms of the interactions among and automatization of these components. At the heart of the componential view is the functioning of the metacomponents, or executive processes, which directly activate and receive feedback from the other kinds of components, in particular, components of performance, acquisition, retrieval, and transfer. These kinds of components interact indirectly with each other through the mediation of the metacomponents.

The componential view (or metatheory) of human intelligence has been instantiated in a number of theories of intellectual task performance, each of which I view as a subtheory of human intelligence considered as a whole, integral entity. These subtheories deal with two broad classes of tasks, those requiring constellations of abilities that can be characterized as fluid and those requiring constellations of abilities that can be characterized as crystallized. This division of tasks is not wholly arbitrary, in that it emerges both from certain psychometric theories of intelligence and from an analysis of people's conceptions of intelligence.

The proposed subtheories of intelligence have been tested via the use of several different kinds of response measures (response time, response choice, error rate, ratings) and on a fairly wide variety of item contents and formats. Results of empirical tests of the task theories have been generally quite favorable, both in an absolute sense and in comparison to alternative theories, although none of the theories can be viewed as "true." In each case, there is statistically significant variance in the data that is not accounted for by the theory.

Future research on intelligence faces a number of difficult questions, among them, the kinds of tasks we ought to be studying and the kinds of methods we ought to be using to study them. I would like to close this section with some final remarks addressing each of these issues as they pertain to my own program of research.

Although virtually all researchers would view both fluid and crystallized abilities as critical in the functioning of adaptive intelligence, the emphasis in my own research program has been very heavily weighted toward the investigation of components of fluid abilities, as exemplified by the reasoning tasks considered above. A high priority for future research, therefore, is to seek a comparable breadth and depth of understanding for tasks drawing upon crystallized abilities, for example, vocabulary and reading comprehension. The emphasis in my research over the next few years, in terms of the kinds of tasks to be studied, will be upon verbal tasks.

Although the componential methodology developed in my previous work has been, I believe, quite highly successful and flexible in studying a variety of fluid-ability tasks and even some more verbally-oriented ones, it almost certainly will need supplementation when brought to bear upon the verbal skills required in academic and practical functioning. Recent "cognitive-science" approaches to cognition, emphasizing as they do the representation of procedural and declarative knowledge, seem to provide the kind of supplementation my largely process-oriented methodology would need for the investigation of verbal performance. The emphasis in my research over the next few years, in terms of methodology for studying tasks, will be to integrate componential and cognitive-scientific methodologies in order to obtain a methodology that is more powerful than either methodology taken by itself. (This integration represents what I see as the next major step for componential analysis, which originally was formulated as an integration of psychometric and information-processing methodologies.)

References

Anderson, J.R. Verbatim and propositional representation of sentences in immediate and long-term memory. Journal of Verbal Learning and Verbal Behavior, 1974, 13, 149-162.

Anderson, J. R. Language, memory, and thought. Hillsdale, N.J.: Erlbaum, 1976.

Anderson, J. R., & Bower, G. H. Human associative memory. Washington, D.C.: Hemisphere Press, 1973.

Ames, W. S. The development of a classification scheme of contextual aids. Reading Research Quarterly, 1966, 2, 57-82.

Aristotle. Poetics. In W. Fyfe (Trans.), Aristotle: The Poetics. Cambridge, Mass.: Harvard University Press, 1927.

Belmont, J. M., & Butterfield, E. C. Learning strategies as determinants of memory deficiencies. Cognitive Psychology, 1971, 2, 411-420.

Billow, R. A cognitive-developmental study of metaphor comprehension. Developmental Psychology, 1975, 11, 415-423.

Black, M. Models and metaphors. Ithaca, N.Y.: Cornell University Press, 1962.

Calfee, R. C. Sources of dependency in cognitive processes. In D. Klahr (Ed.), Cognition and instruction. Hillsdale, N.J.: Erlbaum, 1976.

Campione, J. C., & Brown, A. L. Toward a theory of intelligence: Contributions from research with retarded children. In R. J. Sternberg and D. K. Detterman (Eds.), Human Intelligence: Perspectives on its theory and measurement. Norwood, N.J.: Ablex, 1979.

Carroll, J. B. Words, meanings and concepts. Harvard Educational Review, 1964, 34, 202.

Carroll, J. B. Psychometric tests as cognitive tasks: A new "structure of intellect." In L. B. Resnick (Ed.), The nature of intelligence. Hillsdale, N.J.: Erlbaum, 1976.

Carroll, J. B. How shall we study individual differences in cognitive abilities? Methodological and theoretical perspectives. Intelligence, 1978, 2, 87-115.

Carroll, J. B. Ability and task difficulty in cognitive psychology. Educational Researcher, 1981, 10, 11-21.

Cattell, R. B. Abilities: Their structure, growth, and action. Boston: Houghton-Mifflin, 1971.

Chase, W. G., & Simon, H. A. The mind's eye in chess. In W. G. Chase (Ed.), Visual information processing. New York: Academic Press, 1973.

Chi, M. T. H., Glaser, R., & Rees, E. Expertise in problem solving. In R. J. Sternberg (Ed.), Advances in the psychology of human intelligence (Vol. 1). Hillsdale, N.J.: Erlbaum, in press.

Chiesi, H. L., Spilich, G. J., & Voss, J. F. Acquisition of domain-related information in relation to high and low domain knowledge. Journal of Verbal Learning and Verbal Behavior, 1979, 18, 257-273.

Clark, H. H. Linguistic processes in deductive reasoning. Psychological Review, 1969, 76, 387-404.

Collins, A. M., & Loftus, E. F. A spreading-activation theory of semantic processing. Psychological Review, 1975, 82, 407-429.

Collins, A., & Smith, E. E. Teaching the process of reading comprehension. In D. K. Detterman & R. J. Sternberg (Eds.), How and how much can intelligence be increased? Norwood, N.J.: Ablex, in press.

Cook, J. M., Heim, A. W., & Watts, K. P. The Word-in-Context: A new type of verbal reasoning test. British Journal of Psychology, 1963, 54, 227-237.

Copi, I. M. Introduction to logic (5th ed.). New York: Macmillan, 1978.

Craik, F. I. M. & Lockhart, R. S. Levels of processing: A framework for memory research. Journal of Verbal Learning and Verbal Behavior, 1972, 11, 671-684.

Cronbach, L. J. The two disciplines of scientific psychology. American Psychologist, 1957, 12, 671-684.

Crowder, R. G. Principles of learning and memory. Hillsdale, N.J.: Erlbaum, 1976.

Daalen-Kapteijns, M. M. van, & Elshout-Mohr, M. The acquisition of word meanings as a cognitive learning process. Journal of Verbal Learning and Verbal Behavior, 1981, 20, 386-399.

DeSoto, C. B., London, M., & Handel, S. Social reasoning and spatial paralogic. Journal of Personality and Social Psychology, 1965, 2, 513-521.

Erickson, J. R. A set analysis theory of behavior in formal syllogistic reasoning tasks. In R. Solso (Ed.), Loyola symposium on cognition (Vol. 2). Hillsdale, N.J.: Erlbaum, 1974.

Erickson, J. R. Research on syllogistic reasoning. In R. Revlin & R. E. Mayer (Eds.), Human reasoning. Washington, D.C.: Winston, 1978.

Fischler, J., & Goodman, G. O. Latency of associative activation in memory. Journal of Experimental Psychology: Human Perception and Performance, 1974, 3, 18-26.

Flavell, J. H. Cognitive monitoring. In S. Yussen (Ed.), *The growth of insight in the child*. New York: Academic Press, in press.

Frege, G. On sense and reference. In P. Geach and M. Black (Eds.), *Translations from the philosophical writings of Gottlob Frege*. Oxford: Basil Blackwell & Mott, 1952.

Gentner, D. Children's performance on a spatial analogies task. *Child Development*, 1977, *48*, 1034-1039.

Gipe, J. Investigating techniques for teaching word meanings. *Reading Research Quarterly*, 1979, *4*, 624-644.

Goodman, N. *Fact, fiction, and forecast*. Cambridge, Mass.: Harvard University Press, 1955.

Guilford, J. P. *The nature of human intelligence*. New York: McGraw-Hill, 1967.

Guyote, M. J., & Sternberg, R. J. A transitive-chain theory of syllogistic reasoning. *Cognitive Psychology*, 1981, *13*, 461-525.

Hampton, J. A. Polymorphous concepts in semantic memory. *Journal of Verbal Learning and Verbal Behavior*, 1979, *18*, 441-461.

Heim, A. *Intelligence and personality: Their assessment and relationship.* Harmondsworth, England: Penguin, 1970.

Henley, N. M. A psychological study of the semantics of animal terms. *Journal of Verbal Learning and Verbal Behavior*, 1969, *8*, 176-184.

Hogaboam, T. W., & Pellegrino, J. W. Hunting for individual differences: Verbal ability and semantic processing of pictures and words. *Memory and Cognition*, 1978, *6*, 189-193.

Holyoak, K. J., Glass, A.L., & Mah, W. A. Morphological structure and semantic retrieval. *Journal of Verbal Learning and Verbal Behavior*, 1976, *15*, 235-247.

Horn, J. L. Organization of abilities and the development of intelligence. *Psychological Review*, 1968, *75*, 242-259.

Hunt, E. B. Mechanics of verbal ability. *Psychological Review*, 1978, *85*, 109-130.

Hunt, E. B. Intelligence as an information processing concept. *British Journal of Psychology*, 1980, *71*, 449-474.

Hunt, E. B., Frost, N., & Lunneborg, C. E. Individual differences in cognition: A new approach to intelligence. In G. Bower (Ed.), *Advances in learning and motivation* (Vol. 7). New York: Academic Press, 1973.

Hunt, E. B., Lunneborg, C., & Lewis, J. What does it mean to be high verbal? Cognitive Psychology, 1975, 7, 194-227.

Huttenlocher, J. Constructing spatial images: A strategy in reasoning. Psychological Review, 1968, 75, 550-560.

Huttenlocher, J., & Higgins, E. T. Adjectives, comparatives, and syllogisms. Psychological Review, 1971, 78, 487-504.

Jensen, A. R. g: Outmoded theory or unconquered frontier? Creative Science and Technology, 1979, 2, 16-29.

Jackson, M. D., & McClelland, J. L. Processing determinants of reading speed. Journal of Experimental Psychology: General, 1979, 108, 151-181.

Johnson, D. D., & Pearson, P. D. Teaching reading vocabulary. New York: Holt, 1978.

Johnson-Laird, P. N. The three-term series problem. Cognition, 1972, 1, 57-82.

Katz, J. J. Semantic theory. New York: Harper & Row, 1972.

Keating, D. P., & Bobbitt, B. L. Individual and developmental differences in cognitive-processing components of mental ability. Child Development, 1978, 49, 155-167.

Kintsch, W. The representation of meaning in memory. Hillsdale, N.J.: Erlbaum, 1974.

Lansman, M., Donaldson, G., Hunt, E. B., & Yantis, S. Ability factors and cognitive processes. Intelligence, in press.

MacLeod, C. M., Hunt, E. B., & Mathews, N. N. Individual differences in the verification of sentence-picture relationships. Journal of Verbal Learning and Verbal Behavior, 1978, 17, 493-507.

Malgady, R. C., & Johnson, M. G. Modifiers in metaphors: Effects of constituent phrase similarity on the interpretation of figurative sentences. Journal of Psycholinguistic Research, 1976, 5, 43-52.

Manelis, L., & Thorp, D. A. The processing of affixed words. Memory and Cognition, 1977, 5, 690-695.

Markman, E. M. Realizing that you don't understand: A preliminary investigation. Child Development, 1977, 48, 986-992.

Markman, E. M. Realizing that you don't understand: Elementary school children's awareness of inconsistencies. Child Development, 1979, 50, 643-655.

Markman, E. M. Comprehension monitoring. In S. Yussen (Ed.), The growth of insight in the child. New York: Academic Press, in press.

Matarazzo, J. D. Wechsler's measurement and appraisal of adult intelligence. Baltimore: Williams & Wilkins, 1972.

McCullough, C. M. Context aids in reading. Reading Teacher, 1958, 11, 225-229.

Meyer, D., & Schvaneveldt, R. Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. Journal of Experimental Psychology, 1971, 90, 227-234.

Miller, G. A. Images and models, similies and metaphors. In A. Ortony (Ed.), Metaphor and thought. New York: Cambridge University Press, 1979.

Miller, G. A., & Johnson-Laird, P. N. Language and perception. Cambridge, Mass.: Harvard University Press, 1976.

Mischel, W. Personality and assessment. New York: Wiley, 1968.

Murrell, G. A.,& Morton, J. Word recognition and morphemic structure. Journal of Experimental Psychology, 1974, 102, 963-968.

Newell, A., & Simon, H. A. Human problem solving. Englewood Cliffs, N.J.: Prentice-Hall, 1972.

Nisbett, R. E., & Ross, L. Human inferences: Strategies and shortcomings in social judgment. Englewood Cliffs, N.J.: Prentice-Hall, 1980.

O'Rourke, J. P. Toward a science of vocabulary development. The Hague: Mouton, 1974.

Osgood, C., Suci, G., & Tannenbaum, P. The measurement of meaning. Urbana, Ill.: University of Illinois Press, 1957.

Pellegrino, J. W., & Glaser, R. Components of inductive reasoning. In R. E. Snow, P.-A. Federico, & W. Montague (Eds.), Aptitude, learning and instruction: Cognitive process analyses of aptitude (Vol. 1). Hillsdale, N.J.: Erlbaum, 1980.

Posner, M. I., & Mitchell, R. Chronometric analysis of classification. Psychological Review, 1967, 74, 392-409.

Pellegrino, J. W., & Lyon, D. R. The components of a componential analysis. Intelligence, 1979, 3, 168-186.

Perfetti, C. A., & Lesgold, A. M. Discourse comprehension and individual differences. In P. Carpenter and M. Just (Eds.), Cognitive processes in comprehension: 12th Annual Carnegie Symposium on Cognition. Hillsdale, N.J.: Erlbaum, 1977.

Pressley, M., & Levin, J. R. The keyword method and recall of vocabulary words from definitions. Journal of Experimental Psychology: Human Learning and Memory, 1981, 16, 213-226.

Pressley, M., Levin, J. R., & Miller, G. E. How does the keyword method affect vocabulary comprehension and usage? Reading Research Quarterly, 1981, 16, 213-226.

Pressley, M., Levin, J. R., & Miller, G. E. The keyword method and children's learning of vocabulary with abstract meanings. Canadian Journal of Psychology, in press. (a)

Pressley, M., Levin, J. R., & Miller, G. E. The keyword method compared to alternative vocabulary-learning strategies. Contemporary Educational Psychology, in press. (b)

Quillian, M. R. Semantic memory. In M. Minsky (Ed.), Semantic information processing. Cambridge, Mass.: MIT Press, 1968.

Reder, L. M., & Anderson, J. R. A partial resolution of the paradox of interference: The role of integrating knowledge. Cognitive Psychology, 1980, 12, 447-472.

Reitman, W. Cognition and thought. New York: Wiley, 1965.

Richards, I. A. The philosophy of rhetoric. Oxford: Oxford University Press, 1936.

Rosch, E. Principles of categorization. In E. Rosch and B. B. Lloyd (Eds.), Cognition and categorization. Hillsdale, N.J.: Erlbaum, 1978.

Rubin, D. C. The effectiveness of context before, after, and around a missing word. Perception and Psychophysics, 1976, 19, 214-216.

Rubin, G. S., Becker, C. A., & Freeman, R. H. Morphological structure and its effect on visual word recognition. Journal of Verbal Learning and Verbal Behavior, 1979, 18, 757-767.

Rumelhart, D. E., & Abrahamson, A. A. A model for analogical reasoning. Cognitive Psychology, 1973, 5, 1-28.

Russell, B. On denoting. In R.C. Marsh (Ed.), Logic and knowledge. London: George Allen and Unwin, 1956.

Sapir, J. D. The anatomy of metaphor. In J.D. Sapir and J.C. Crocker (Eds.), The social use of metaphor: Essays on the anthropology of rhetoric. Philadelphia: University of Pennsylvania Press, 1977.

Schank, R. How much intelligence is there in artificial intelligence? Intelligence, 1980, 4, 1-14.

Schank, R. C., & Abelson, R. Scripts, plans, goals, and understanding. Hillsdale, N.J.: Erlbaum, 1977.

Schustack, M. W., & Sternberg, R.J. Evaluation of evidence in causal inference. *Journal of Experimental Psychology*: *General*, 1981, *110*, 101-120.

Schwartz, S. P. *Naming, necessity, and natural kinds*. Ithaca, N.Y.: Cornell University Press, 1977.

Shaver, P., Pierson, L., & Lang, S. Converging evidence for the functional significance of imagery in problem solving. *Cognition*, 1974, *3*, 359-375.

Shepard, R. The analysis of proximities: Multidimensional scaling with an unknown distance function. I. *Psychometrika*, 1962, *27*, 125-140.

Shumway, N., & Forbes, R. D. *Español en español*. In press.

Smith, E. E., Adams, N., & Schorr, D. Fact retrieval and the paradox of interference. *Cognitive Psychology*, 1978, *10*, 438-464.

Smith, E. E., Shoben, E. J., & Rips, L. J. Structure and process in semantic memory: A featural model for semantic decision. *Psychological Review*, 1974. *81*, 214-241.

Smith, H. K. The response of good and poor readers when asked to read for different purposes. *Reading Research Quarterly*, 1967, *3*, 53-83.

Snow, R. E. Theory and method for research on aptitude processes. *Intelligence*, 1978, *2*, 225-278.

Spearman, C. *The nature of 'intelligence' and the principles of cognition*. London: Macmillan, 1923.

Stanners, R. F., Neiser, J. J., & Painton, S. Memory representation for prefixed words. *Journal of Verbal Learning and Verbal Behavior*, 1979, *18*, 733-743.

Sternberg, R. J. *How to prepare for the Miller Analogies Test*. Woodbury, N.Y.: Barron's Educational Series, Inc., 1974.

Sternberg, R. J. Component processes in analogical reasoning. *Psychological Review*, 1977, *84*, 353-378. (a)

Sternberg, R. J. *Intelligence, information processing and analogical reasoning: The componential analysis of human abilities*. Hillsdale, N.J.: Erlbaum, 1977. (b)

Sternberg, R. J. The nature of mental abilities. *American Psychologist*, 1979, *37*, 214-230.

Sternberg, R. J. The development of linear syllogistic reasoning. *Journal of Experimental Child Psychology*, 1980, *29*, 340-356. (a)

Sternberg, R. J. A proposed resolution of curious conflicts in the literature on linear syllogisms. In R. Nickerson (Ed.), Attention and Performance VIII. Hillsdale, N.J.: Erlbaum, 1980. (b)

Sternberg, R. J. Representation and process in linear syllogistic reasoning. Journal of Experimental Psychology: General, 1980, 109, 119-159. (c)

Sternberg, R. J. Sketch of a componential subtheory of human intelligence. Behavioral and Brain Sciences, 1980, 3, 573-584. (d)

Sternberg, R. J. The evolution of theories of intelligence. Intelligence, 1981, 5, 209-229. (a)

Sternberg, R. J. Intelligence and nonentrenchment. Journal of Educational Psychology, 1981, 73, 1-16. (b)

Sternberg, R. J. Reasoning with determinate and indeterminate linear syllogisms. British Journal of Psychology, 1981, 72, 407-420. (c)

Sternberg, R. J. Testing and cognitive psychology. American Psychologist, 1981, 36, 1181-1189. (d)

Sternberg, R. J. Natural, unnatural and supernatural concepts. Cognitive Psychology, 1982, M, 451-488.

Sternberg, R.J., Conway, B. E., Ketron, J. L., & Bernstein, M. People's conceptions of intelligence. Journal of Personality and Social Psychology: Attitudes and Social Cognition, 1981, 41, 37-55.

Sternberg, R. J., & Gardner, M. K. A componential interpretation of the general factor in human intelligence. In H. J. Eysenck (Ed.), A model for intelligence. Berlin: Springer, 1982.

Sternberg, R. J. & Gardner, M. K. Unities in inductive reasoning. Journal of Experimental Psychology: General, 1983, 112, 80-116.

Sternberg, R. J. & Nigro, G. Developmental patterns in the solution of verbal analogies. Child Development, 1980, 51, 27-38.

Sternberg, R. J. Interaction and analogy to the comprehension and appreciation of metaphors. Quarterly Journal of Experimental Psychology: Human Experimental Psychology, in press.

Sternberg, R. J. & Rifkin, B. The development of analogical reasoning processes. Journal of Experimental Child Psychology, 1979, 27, 195-232.

Sternberg, R. J. & Schustack, M. W. Components of causal inference. Naval Research Reviews, 1980, 33, 48-62.

Sternberg, R. J., Tourangeau, R., & Nigro, G. Metaphor, induction, and social policy: The convergence of macroscopic and microscopic views. In A. Ortony (Ed.), Metaphor and thought. New York: Cambridge University Press, 1979.

Sternberg, R. J., and Turner, M. E. Components of syllogistic reasoning. Acta Psychologica, 1981, 47, 245-265.

Sternberg, R. J., & Weil, E. M. An aptitude-strategy interaction in linear syllogisitc reasoning. *Journal of Educational Psychology*, 1980, *72*, 226-234.

Sternberg, S. The discovery of processing stages: Extensions of Donders' method. *Acta Psychologica*, 1969, 30, 276-315.

Swinney, D. A. Lexical access during sentence comprehension: (Re)consideration of context effects. *Journal of Verbal Learning and Verbal Behavior*, 1979, *18*, 645-659.

Taft, M. Recognition of affixed words and the word frequency effect. *Memory and Cognition*, 1979, *7*, 263-272.

Taft, M. Prefix stripping revisited. *Journal of Verbal Learning and Verbal Behavior*, 1981, *20*, 289-297.

Taft, M., & Forster, K. I. Lexical storage and retrieval of prefixed words. *Journal of Verbal Learning and Verbal Behavior*. 1975, *14*, 638-647.

Thurstone, L. L. *Primary mental abilities*. Chicago: University of Chicago Press, 1938.

Tourangeau, R., & Sternberg, R. J. Aptness in metaphor. *Cognitive Psychology*, 1981, *13*, 27-55.

Tourangeau, R., & Sternberg, R. J. Understanding and appreciating metaphors. *Cognition*, in press.

Tversky, A., & Kahneman, D. Belief in the law of small numbers. *Psychological Bulletin*, 1971, *76*, 105-110.

Tversky, A., & Kahneman, D. Availability: A heuristic for judging frequency and probability. *Cognitive Psychology*, 1973, *5*, 207-232.

Tversky, A., & Kahneman, D. Judgment under uncertainty: Heuristics and biases. *Science*, 1974, *185*, 1124-1131.

Verbrugge, R., & McCarrell, N. Metaphoric comprehension: Studies in reminding and resembling. *Cognitive Psychology*, 1977, *9*, 494-533.

Vernon, P. E. *The structure of human abilities*. London: Methuen, 1971.

Wason, P. C. On the failure to eliminate hypotheses in a conceptual task. *Quarterly Journal of Experimental Psychology*, 1960, *12*, 129-140.

Wason, P. C., & Johnson-Laird, P. N. *Psychology of reasoning*: *Structure and content*. London: D.T. Batsford, 1972.

Werner, H., & Kaplan, E. The acquisition of word meanings: A developmental study. *Monographs of the Society for Research in Child Development*, 1952, No. 51.

Wittgenstein, L. *Philosophical investigations*. Oxford: Basil Blackwell & Mott, 1953.

Wood, D., Shotter, J., & Godden, D. An investigation of the relationships between problem-solving strategies, representation and memory. *Quarterly Journal of Experimental Psychology*, 1974, *26*, 252-257.

Regular Publications

1978

Sternberg, R. J. Isolating the components of intelligence. Intelligence, 1978, 2, 117-128.

Sternberg, R. J. Intelligence research at the interface between differential and cognitive psychology. Intelligence, 1978, 2, 195-222.

1979

Sternberg, R. J. Is absolute time relatively interesting? Behavioral and Brain Sciences, 1979, 2, 281-282.

Sternberg, R. J. The nature of mental abilities. American Psychologist, 1979, 1979, 34, 214-230.

Sternberg, R. J. Six authors in search of a character: A play about intelligence tests in the year 2000. Intelligence, 1979, 3, 281-291

Sternberg, R. J. Stalking the I.Q. quark. Psychology Today, 1979, 13, 42-54.

Sternberg, R. J., & Detterman, D. K. (Eds.). Human intelligence: Perspectives on its theory and measurement. Norwood, N.J.: Ablex, 1979.

Sternberg, R. J., Tourangeau, R., & Nigro, G. Metaphor, induction, and social policy: The convergence of macroscopic and microscopic views. In A. Ortony (Ed.), Metaphor and thought. New York: Cambridge University Press, 1979.

1980

Sternberg, R. J. The cat in the hat comes back. Review of C. R. Puff (Ed.), Memory organization and structure. Contemporary Psychology, 1980, 25, 690-691.

Sternberg, R. J. Claims, counterclaims, and components: A countercritique of componential analysis. Behavioral and Brain Sciences, 1980, 3, 599-611.

Sternberg, R. J. Componentman as vice-president: A reply to Pellegrino and Lyon's analysis of "The components of a componential analysis." Intelligence, 1980, 4, 83-95.

Sternberg, R. J. The construct validity of aptitude tests: An information-processing assessment. In Construct validity in psychological measurement. Princeton: Educational Testing Service, 1980.

Sternberg, R. J. Factor theories of intelligence are all right almost. Educational Researcher, 1980, 9, 6-13, 18.

Sternberg, R. J. Intelligence and test bias: Art and science. Behavioral and Brain Sciences, 1980, 3, 353-354.

Sternberg, R. J. A proposed resolution of curious conflicts in the literature on linear syllogisms. In R. Nickerson (Ed.), Attention and performance VIII. Hillsdale, N.J.: Erlbaum, 1980.

Sternberg, R. J. Representation and process in linear syllogistic reasoning. Journal of Experimental Psychology: General, 1980, 109, 119-159.

Sternberg, R. J. Review of W. A. Scott, D. W. Osgood, & C. Peterson, Cognitive structure: Theory and measurement of individual differences. American Scientist, 1980, 68, 459-460.

Sternberg, R. J. Sketch of a componential subtheory of human intelligence. Behavioral and Brain Sciences, 1980, 3, 573-584.

Sternberg, R. J. A tower of intellect? Review of A. Chiba, Developmental structure of intelligence. Contemporary Psychology, 1980, 25, 389-390.

Sternberg, R. J., & Gardner, M. K. Information processing components of general intelligence. Human Intelligence International Newsletter, 1980, 1, 3.

1980

Sternberg, R. J., Guyote, M. J., & Turner, M. E. Deductive reasoning. In R. E. Snow, P.-A. Federico, & W. Montague (Eds.), *Aptitude, learning, and instruction: Cognitive process analyses of aptitude* (Vol. 1). Hillsdale, N.J.: Erlbaum, 1980.

Sternberg, R. J., & Schustack, M. W. Components of causal inference. *Naval Research Reviews*, 1980, *33*, 48-62.

Sternberg, R. J., & Weil, E. M. An aptitude-strategy interaction in linear syllogistic reasoning. *Journal of Educational Psychology*, 1980, *72*, 226-234.

1981

Guyote, M. J., & Sternberg, R. J. A transitive-chain theory of syllogistic reasoning. *Cognitive Psychology*, 1981, *13*, 461-525.

Schustack, M. W., & Sternberg, R. J. Evaluation of evidence in causal inference. *Journal of Experimental Psychology: General*, 1981, *110*, 101-120.

Sternberg, R. J. A componential theory of intellectual giftedness. *Gifted Child Quarterly*, 1981, *25*, 86-93.

Sternberg, R. J. The evolution of theories of intelligence. *Intelligence*, 1981, *5*, 209-229.

Sternberg, R. J. Intelligence and nonentrenchment. *Journal of Educational Psychology*, 1981, *73*, 1-16.

Sternberg, R. J. Intelligence as thinking and learning skills. *Educational Leadership*, 1981, *39*, 18-20.

Sternberg, R. J. The nature of intelligence. *New York University Education Quarterly*, 1981, *12*, 3, 10-17.

Sternberg, R. J. Nothing fails like success: The search for an intelligent paradigm for studying intelligence. *Journal of Educational Psychology*, 1981, *73*, 142-155.

Sternberg, R. J. Novelty-seeking, novelty-finding, and the developmental continuity of intelligence. *Intelligence*, 1981, *5*, 149-155.

Sternberg, R. J. Reasoning with determinate and indeterminate linear syllogisms. *British Journal of Psychology*, 1981, 407-420.

Sternberg, R. J. Some questions regarding the rationality of a demonstration of human rationality. *Behavioral and Brain Sciences*, 1981, *4*, 352-353.

Sternberg, R. J. Testing and cognitive psychology. *American Psychologist*, 1981, *36*, 1181-1189.

Sternberg, R. J. Toward a unified componential theory of human intelligence: I. Fluid abilities. In M. Friedman, J. Das, & N. O'Connor (Eds.), *Intelligence and learning*. New York: Plenum, 1981.

Sternberg, R. J., Conway, B. E., Ketron, J. L., & Bernstein, M. People's conceptions of intelligence. *Journal of Personality and Social Psychology: Attitudes and Social Cognition*, 1981, *41*, 37-55.

Sternberg, R. J., & Turner, M. E. Components of syllogistic reasoning. *Acta Psychologica*, 1981, *47*, 245-265.

Tourangeau, R., & Sternberg, R. J. Aptness in metaphor. *Cognitive Psychology*, 1981, *13*, 27-55.

1982

Detterman, D. K., & Sternberg, R. J. (Eds.). *How and how much can intelligence be increased?* Norwood, N.J.: Ablex, 1982.

Sternberg, R. J. (Ed.). *Advances in the psychology of human intelligence* (Vol. 1). Hillsdale, N.J.: Erlbaum, 1982.

Sternberg, R. J. Casting stones: A reply to Humphreys. *Journal of Educational Psychology*, 1982, *74*, 427-429.

1982

Sternberg, R. J. A componential approach to intellectual development. In R. J. Sternberg (Ed.), *Advances in the psychology of human intelligence* (Vol. 1). Hillsdale, N.J.: Erlbaum, 1982.

Sternberg, R. J. Nonentrenchment in the assessment of intellectual giftedness. *Gifted Child Quarterly*, 1982, *26*, 63-67.

Sternberg, R. J. Teaching scientific thinking to gifted children. *Roeper Review*, 1982, *4* April-May, 4-6.

Sternberg, R. J., & Davidson, J. E. Componential analysis and componential theory. *Behavioral and Brain Sciences*, 1982, *5*, 352-353.

Sternberg, R. J., & Downing, C. J. The development of higher-order reasoning in adolescence. *Child Development*, 1982, *53*, 209-221.

Sternberg, R. J., & Ketron, J. L. Selection and implementation of strategies in reasoning by analogy. *Journal of Educational Psychology*, 1982, *74*, 399-413.

Sternberg, R. J., Ketron, J. L., & Powell, J. S. Componential approaches to the training of intelligent performance. In D. K. Detterman & R. J. Sternberg (Eds.), *How and how much can intelligence be increased?* Norwood, N.J.: Ablex, 1982.

Tourangeau, R., & Sternberg, R. J. Understanding and appreciating metaphors. *Cognition*, 1982, *11*, 203-244.

In press

Sternberg, R. J. (Ed.). *Advances in the psychology of human intelligence* (Vol. 2). Hillsdale, N.J.: Erlbaum, in press.

Sternberg, R. J. (Ed.). *Approaches to individual differences*. Hillsdale, N.J.: Erlbaum, in press.

Sternberg, R. J. Common and uncommon issues in AI and psychology. In A. Elithorn (Ed.), *Artificial and human intelligence*. New York: Plenum, in press.

Sternberg, R. J. (Ed.) *Handbook of human intelligence*. New York: Cambridge University Press, in press.

Sternberg, R. J. (Ed.) *Human abilities: An information-processing approach*. San Francisco: Freeman, in press.

Sternberg, R. J. Instrumental and componential approaches to the training of intelligence. In S. Chipman, J. Segal, & R. Glaser (Eds.), *Thinking and learning skills: Current research and open questions* (Vol. 1). Hillsdale, N.J.: Erlbaum, in press.

Sternberg, R. J. Intelligence. In R. Gregory (Ed.), *Oxford companion to the human mind*. Oxford: Oxford University Press, in press.

Sternberg, R. J. "Metacognitive assessment:" An assessment. In S. Yussen (Ed.), *The growth of insight in the child*. New York: Academic Press, in press.

Sternberg, R. J. Natural, unnatural, and supernatural concepts. *Cognitive Psychology*, in press.

Sternberg, R. J. Reasoning, problem solving, and intelligence. In R. J. Sternberg (Ed.), *Handbook of human intelligence*. New York: Cambridge University Press, in press.

Sternberg, R. J. Transition mechanisms in cognitive development: A componential approach. *Child Development*, in press.

Sternberg, R. J., & Davidson, J. E. Competence and performance in intellectual development. In E. Neimark, R. de Lisi, & J.H. Newman (Eds.), *Moderators of competence*. Hillsdale, N.J.: Erlbaum, in press.

Sternberg, R. J. Programs that train intellectual skills: Some prerequisites. In A. Morles (Ed.), *Intelligence and its development*. Caracas, Venezuela: CINTERPLAN, in press.

In press

Sternberg, R. J., & Gardner, M. K. A componential interpretation of the general factor in human intelligence. In H. J. Eysenck (Ed.), *A model for intelligence*. Munich: Springer, in press.

Sternberg, R. J., & Kaye, D. B. Intelligence. In H. Mitzel (Ed.), *Encyclopedia of educational research* (5th ed.). Washington, D.C.: American Educational Research Association, in press.

Sternberg, R. J., & Lasaga, M. Approaches to human reasoning: An analytical framework. In A. Elithorn (Ed.), *Artificial and human intelligence*. New York: Plenum, in press.

Sternberg, R. J., & Nigro, G. Interaction and analogy in the comprehension and appreciation of metaphors. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, in press.

Sternberg, R. J., & McNamara, T. P. The representation and processing of information in real-time verbal comprehension. In S. E. Whitely (Ed.), *Test design: Contributions from psychology, education, and psychometrics*. New York: Academic Press, in press.

Sternberg, R. J., & Powell, J. S. Theories of intelligence. In R. J. Sternberg (Ed.), Handbook of human intelligence. New York: Cambridge University Press, in press.

Sternberg, R. J., Powell, J. S., & Kaye, D. B. The nature of verbal comprehension. *Poetics*, in press.

Sternberg, R. J., Powell, J. S., & Kaye, D. B. Teaching vocabulary-building skills: A contextual approach. In A. C. Wilkinson (Ed.), *Communicating with computers in classrooms: Prospects for applied cognitive science*. New York: Academic Press, in press.

Sternberg, R. J., & Salter, W. Conceptions of intelligence. In R. J. Sternberg (Ed.), *Handbook of human intelligence*. New York: Cambridge University Press, in press.

Technical Reports

1978

1. Sternberg, R. J. *Intelligence research at the interface between differential and cognitive psychology.*
2. Sternberg, R. J. *Isolating the components of intelligence.*
3. Sternberg, R. J., Guyote, M. J., & Turner, M. E. *Deductive reasoning.*
4. Sternberg, R. J. *Toward a unified componential theory of human reasoning.*
5. Guyote, M. J., & Sternberg, R. J. *A transitive-chain theory of syllogistic reasoning.*
6. Sternberg, R. J., & Turner, M. E. *Components of syllogistic reasoning.*
7. Sternberg, R. J., Tourangeau, R., & Nigro, G. *Metaphor, induction, and social policy.*
8. Sternberg, R. J. *A proposed resolution of curious conflicts in the literature on linear syllogisms.*
9. Sternberg, R. J. *The nature of mental abilities.*
10. Sternberg, R. J. *Psychometrics, mathematical psychology, and cognition: Confessions of a closet psychometrician.*
11. Tourangeau, R., & Sternberg, R. J. *Understanding and appreciating metaphors.*
12. Sternberg, R. J. *Representation and process in transitive inference.*
13. Tourangeau, R., & Sternberg, R. J. *Aptness in metaphor.*
14. Sternberg, R. J. *Contrasting conceptions of intelligence and their educational implications.*

1979

15. Sternberg, R. J., & Weil, E. M. *An aptitude-strategy interaction in linear syllogistic reasoning.*
16. Sternberg, R. J. *Intelligence tests in the year 2000: What forms will they take and what purposes will they serve?*
17. Sternberg, R. J. *New views on I.Q.s: A silent revolution of the 70s.*
18. Sternberg, R. J., & Gardner, M. K. *Unities in inductive reasoning.*
19. Sternberg, R. J. *Components of human intelligence.*
20. Sternberg, R. J. *The construct validity of aptitude tests: An information-processing assessment.*
21. Schustack, M. W., & Sternberg, R. J. *Evaluation of evidence in causal inference.*

1980

22. Sternberg, R. J., Powell, J. S., & Ketron, J. L. *Componential approaches to the training of intelligent performance.*
23. Sternberg, R. J. *Intelligence and nonentrenchment.*
24. Sternberg, R. J. *Reasoning, problem solving, and intelligence.*
25. Sternberg, R. J. *Claims, counterclaims, and components: A countercritique of componential analysis.*
26. Sternberg, R. J., & Nigro, G. *Interaction and analogy in the comprehension and appreciation of metaphors.*
27. Sternberg, R. J. *The nature of intelligence.*
28. Sternberg, R. J., Conway, B. E., Ketron, J. L., & Bernstein, M. *People's conceptions of intelligence.*
29. Sternberg, R. J. *Nothing fails like success: The search for an intelligent paradigm for studying intelligence.*
30. Sternberg, R. J. *Reasoning with determinate and indeterminate linear syllogisms.*
31. Sternberg, R. J., & Gardner, M. K. *A componential interpretation of the general factor in human intelligence.*

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